Newman

NUREG-0782
Vol. 1

Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Summary

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

Available from

GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, DC 20555

and

National Technical Information Service
Springfield, VA 22161

NUREG-0782
Vol. 1

Draft Environmental Impact Statement
on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Summary

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

FOREWORD

The evaluations and analyses set out in Volume II of this EIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design and method of operation of disposal facilities, institutional controls, financial assurances, and administrative and procedural requirements. Rather than presenting the results of the individual analysis of alternatives, this summary draws on the various analyses and presents the collective major conclusions, findings, and recommendations that have been derived and incorporated into the Part 61 rule. It is not possible to present the rationale or to summarize all the requirements in this summary. NRC has, therefore, concentrated on the major requirements of the rule--the performance objectives and technical requirements that establish the controls to be applied in disposal of waste. The discussion often cross-references specific sections or paragraphs of the proposed rule, which is included as Attachment A to this summary.

The results of the analyses carried out in this EIS indicate that, with modest increases in cost relating to improving the form and properties of waste shipped for disposal (most of which are essentially being implemented today) and modest improvements in the design and operation of a near-surface disposal facility (many of which are being used at some of the existing sites today), the potential health, safety, and environmental impacts from disposal of LLW and the degree of long-term social commitment can be reduced. The ability to predict the long-term performance and impacts of near-surface disposal facilities is also improved, and the uncertain and high costs required to care for disposal sites over the long term are reduced.

Stated simply, we can put some modest increased effort and cost into the disposal of LLW today--leading to reduction in potential impacts, reduction in long-term care costs, and increased confidence in the performance capability of near-surface disposal facilities. Or, we can continue as we have in the past, possibly leading to situations as has been evidenced at some existing sites where the potential impacts over the long term may be high, the costs for long-term care high, and confidence in the long-term performance low. The proper course of action is the former, and the performance objectives, technical, and other requirements selected and set out in the new Part 61 regulation and in amendments to other existing parts of NRC's regulations are directed at these key aspects.

VOLUME I

Summary

Table of Contents (Continued)

List of Tables

Table of Contents (Continued)

Page

List of Figures

Figures

SUMMARY

1. DESCRIPTION OF THE PROPOSED ACTION--PURPOSE, SCOPE, NEED, AND STRUCTURE OF THE EIS

The proposed action being considered in this environmental impact statement (EIS) is the issuance of a new regulation, Part 61, to the U.S. Nuclear Regulatory Commission (NRC) rules in Title 10, Code of Federal Regulations (10 CFR). Part 61 will provide licensing procedures, performance objectives, and technical requirements for the issuance of licenses for the land disposal of "low-level" radioactive waste (LLW). Specifically, the proposed action includes consideration of requirements on the standards of performance that should be met in land disposal; technical requirements for the siting, design, operation, closure and postoperational activities for a near-surface disposal facility; technical requirements on waste form that waste generators would be required to meet for acceptance of waste at a disposal facility; classification of waste; administrative and procedural requirements for licensing a disposal facility; and provisions for adequate financial assurance.

1.1 Purpose

NRC has a two-fold purpose in preparing this EIS. First, it is to fulfill NRC's responsibility under the National Environmental Policy Act of 1969 (NEPA). NEPA requires that a federal agency prepare an EIS for "major actions significantly affecting the quality of the human environment." NRC has determined that the promulgation of Part 61 is such an action and this EIS has, therefore, been prepared.

Second, NRC has prepared this EIS to demonstrate the decision processes applied in the development of Part 61. It is the intent of NEPA to have federal agencies consider alternatives and to incorporate environmental values into the decision-making process at an early stage. NRC has analyzed alternative courses of action, and requirements were selected with consideration of costs, environmental impacts, and health and safety effects to current and future generations.

1.2 Scope

This EIS analyzes requirements for the land disposal of radioactive waste and specifically, near-surface disposal. Near-surface disposal involves disposal in the uppermost 15 to 20 meters of the earth's surface. Specific technical requirements for other alternative land disposal methods (e.g., deep-mined cavities) will be addressed in subsequent rulemaking actions. It also does not address other methods such as ocean and space disposal. Requirements for ocean disposal are a responsibility of the Environmental Protection Agency. Space disposal, although feasible, is not developed to the point of routine technical and economic application.

This EIS is not a generic EIS in that it does not analyze all of the issues involved in the disposal of LLW. Rather, this EIS provides the decision analysis for requirements in the Part 61 rule. Only issues that are germane to this decision process are analyzed and considered.

1.3 Need for the Proposed Action

Current NRC regulations for licensing radioactive materials do not contain sufficient technical standards or criteria for the disposal of the licensed materials as waste. As discussed below, the need for comprehensive national standards and technical criteria for the disposal of radioactive waste is well documented.

Performance objectives are needed to define the level of safety, environmental protection, and social commitment that should be achieved in the disposal of LLW. To ensure that the performance objectives are met, technical requirements are needed regarding the siting, design, operation, and closure of a LLW disposal facility. Requirements on postclosure activities are also needed, as are requirements on the form, packaging, and content of the disposed waste. Administrative and procedural requirements for licensing a LLW disposal facility should be reviewed and changes evaluated. Finally, requirements for financial assurance need to be evaluated to assure adequate financial resources for closure and postclosure activities.

Comprehensive standards, technical criteria, and licensing procedures are thus needed. They are needed to assure the public health and safety and long-term environmental protection in the licensing of new disposal sites. They are also needed with respect to operation of the existing sites and with respect to final closure and stabilization of all sites.

In evaluating the level of safety which should be achieved, NRC identified 3 principal components that needed to be considered:

1. Protection of occupationally exposed workers and the public during operation of the facility;

2. long-term environmental protection; and

3. Protection of an inadvertent intruder.

A level of safety has been established for occupationally exposed workers and protection of the public during operation of the facility and is set out in the existing standards in 10 CFR Part 20, which applies to the activities of all NRC licensees.

Neither the federal government nor any national and international organizations have, however, defined such a level of safety specific to the disposal of LLW involving long-term environmental protection and protection of an inadvertent intruder. NRC thus had to establish performance objectives to define the level of safety which should be achieved for each of these. Protection of an inadvertent intruder is a new concept, generally unique to disposal of waste. With respect to standards on long-term releases to the environment, the Environmental Protection Agency is developing such standards through its overall program to develop generally applicable environmental standards; however, no standard for LLW disposal presently exists.

In addition, there was a fourth component, generally unique to waste disposal that also needed to be addressed: long-term social commitment. Future generations should not be burdened with long-term expensive commitments to care for wastes generated today, and the development of requirements for the disposal of waste should take into account the long-term commitment of social and natural resources to care for waste over the long term.

1.4 Structure of the EIS

This EIS has been prepared in accordance with requirements of the National Environmental Policy Act. It has also been prepared following Council on Environmental Quality (CEQ) regulations for preparation of environmental impact statements and NRC implementing regulations as set out in 10 CFR Part 51, "Licensing and Regulatory Policy and Procedures for Environmental Protection."

This EIS is being published in four separate volumes. Volume I is this summary. Attachment A to this summary is the proposed Part 61 rule. Volume II contains the main text which consists of ten chapters described in greater detail below. Volumes III and IV contain appendices A-Q which set out details and other supporting technical information to that contained in the main text. The chapters and appendices are frequently referenced in this summary.

Chapter 1 of the main text is an introduction which presents background information about LLW disposal and the purpose, scope, and structure of this EIS. Chapter 2 presents the overall approach NRC has followed in developing regulations for LLW disposal. Chapter 3 describes the affected environment and the technical approach followed in this EIS in analyzing LLW disposal. Chapter 4 presents and analyzes alternatives regarding protection of an individual who might inadvertently intrude into a disposal facility at a future time. Chapter 5 presents and analyzes alternatives relating to long-term environmental protection and potential releases to the environment from a disposal facility. Chapter 6 presents and analyzes alternatives relating to safety during operation of the facility. Chapter 7 presents the classification of waste for near-surface disposal, defining those wastes which are acceptable for disposal by near-surface disposal methods and those wastes which are generally not acceptable and must be disposed of by other methods. Chapter 8 presents the regulatory program for licensing the land disposal of radioactive wastes. Chapter 9 presents and analyzes requirements for financial assurance. Chapter 10 presents typical unmitigated impacts of Part 61 through analysis of the disposal of waste on a regional basis following the preferred technical requirements identified in this EIS.

1.5 Scoping for the EIS

Scoping of an environmental impact statement is defined by the Council on Environmental Quality in 40 CFR Part 501.7 as "...an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action." Although the concept of EIS scoping is a relatively recent development, NRC has conducted scoping activities relative to the proposed Part 61 and this EIS since 1978. Included have been:

1. Public comments in response to an Advance Notice of Proposed Rulemaking on the LLW Disposal Regulation (10 CFR Part 61) published in the Federal Register on October 28, 1978;

2. Public comments on a preliminary draft of 10 CFR Part 61 dated November 5, 1979;

3. Four regional workshops on Part 61 sponsored by the Southern States Energy Board, the Western Interstate Energy Board, the Midwest Regional Office of the Council of State Governments and the New England Regional Commission;

4. Input from the State Planning Council, the National Governors Association, the National Council of State Legislators, and the National Conference of State Radiation Control Program Directors;

5. A Natural Resources Defense Council Petition for Rulemaking;

6. Discussions with industry, public interest groups, state and federal agencies, and others;

7. Licensing experience and current LLW management techniques at existing disposal sites;

8. Programs of the Environmental Protection Agency to develop standards for LLW disposal and regulations for disposal of nonradioactive solid and chemically hazardous wastes; and

9. The results of federal, state, and other organization's studies and technical data on LLW management and disposal.

Public participation in the development of Part 61 and analyses of the major scoping activities and public comments are discussed in Appendix C.

2. DESCRIPTION OF THE AFFECTED ENVIRONMENT

The environment affected or potentially affected by the generation, transport, and disposal of LLW encompasses the whole of the nuclear industry and much of society. It consists of all the industries, hospitals, private individuals, and governmental agencies and laboratories that generate LLW through the use of radioactive materials as a normal part of their day-to-day activities and functions. It consists of those involved in supplying waste processing and packaging services at waste generator facilities, and transporting waste from waste generators to disposal facilities. It consists of those involved in the ownership, operation, and long-term control of the disposal facilities. It involves the various regulatory agencies such as NRC, the Department of Transportation (DOT) and the state radiation control programs that license, regulate, and inspect all waste management phases to assure an adequate level of safety. In consists of society: the individuals, small population groups, and the general population that can be potentially affected by the various activities involved in the generation and disposal of waste. Finally, it consists of the natural environment including the ground and surface water, the atmosphere, and various plant and animal species that would be affected by site-specific activities.

2.1 Waste Generation and Characteristics

The term "low-level waste" serves as a general term for a very wide range of radioactive wastes. All industries; hospitals; medical, educational, or research institutions; private or government laboratories; or facilities forming part of the nuclear fuel cycle (e.g., nuclear power plants, fuel fabrication plants) utilizing radioactive materials as a part of their normal operational activities generate so-called low-level radioactive waste just as they generate other types of hazardous and nonhazardous waste. LLW consists of the radioactive materials themselves and other materials which have been in contact with radioactive material and are contaminated or suspected of being contaminated.

Presently, there are more than 20,000 companies, institutions, laboratories, and government facilities licensed by NRC or Agreement States to use radioactive materials as a normal part of day-to-day activities. Because of the wide range in the types of activities and in specific purposes of application, LLW is generated in many waste types, forms, and amounts. It ranges from trash that is only suspected of being contaminated to highly radioactive material such as activated structural components from nuclear power reactors. The form of the generated waste can be solid, liquid, or gaseous. It can consist of a wide range of chemical forms and can be shipped in a number of different types of packages.

Currently, about 85,000 m^3 (3 million ft^3) of "commercial" LLW is generated annually. It ranges in activity from thousands of curies per cubic meter to less than a few microcuries per cubic meter. Most of the activity disposed of at the commercial sites is contained in a relatively small volume of waste which is generated by less than 100 licensees. Based on projections of LLW volume prepared by NRC for the basic waste streams considered in this EIS, about 3.62 million m^3 (128 million ft^3) will be generated during the period 1980-2000. Of this, about 65% of the waste is projected to be generated by fuel cycle sources and 35% by nonfuel cycle sources. Institutional generators will account for about 19% of the nonfuel cycle sources.

2.2 Waste Disposal

The operators of the disposal facilities offer the essential services of providing a licensed and controlled site for disposal of radioactive waste. The waste is disposed of by a method generally known as shallow land burial (SLB). This method of waste disposal consists of placing packaged waste into excavated trenches. The filled trenches are backfilled with soil, capped, and mounded to facilitate rainwater runoff.

Presently, there are 6 commercial sites: 3 operating and 3 closed. One of the operating sites, located at Barnwell, South Carolina, is operated by Chem-Nuclear Systems, Inc. The other two operating sites, located at Beatty, Nevada and Richland, Washington are operated by U.S. Ecology, Inc. (formerly the Nuclear Engineering Company, Inc.). The commerical sites are summarized in Table S.1 below. The Department of Energy (DOE) also operates 14 sites throughout the country for the disposal of wastes generated from defense and DOE research and development activities. These 14 sites are not subject to NRC regulatory jurisdiction.

Table S.1 Commercial Waste Disposal Sites

Location	Operator	Originally Licensed By (year)	Currently Licensed By	Operational Status
Beatty, Nevada	U.S. Ecology, Inc.	AEC (1962)	State	Open
Maxey Flats, Kentucky	U.S. Ecology, Inc.*	Kentucky (1962)	State	Closed
West Valley, New York	Nuclear Fuel Services, Inc.	New York (1963)	State	Closed
Richland, Washington	U.S. Ecology, Inc.	AEC (1965)	State and NRC**	Open
Sheffield, Illinois	U.S. Ecology, Inc.	AEC (1967)	NRC	Closed
Barnwell, S. Carolina	Chem-Nuclear Systems, Inc.	South Carolina (1971)	State and NRC**	Open

*U.S. Ecology was the operator while the site was open. Currently, Hittman, Inc. maintains the site as a caretaker for the state of Kentucky.
**NRC licenses only special nuclear material.

2.3 Federal and State Responsibilities in Commercial LLW Disposal

There are five key federal agencies that administer programs regarding the management and disposal of LLW. These include the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS) in the Department of Interior, the Department of Energy (DOE), and the Department of Transportation (DOT).

NRC has the responsibility in the United States of regulating and licensing the commercial and nondefense governmental use of source, byproduct, and special nuclear material. This responsibility extends to licensing commercial disposal of LLW in licensed facilities. NRC carries out its responsibilities in compliance with overall federal radiation protection guidance and environmental standards established by the Environmental Protection Agency. EPA was charged with this responsibility in the Reorganization Plan Number Three of 1970. The U.S. Geological Survey is responsible for basic research in the geological sciences and development of basic data for application in the development of criteria and to provide technical advice in the assessment of specific disposal sites. The Department of Energy carries out federal responsibilities for the research, development, and transfer of LLW disposal technology to commercial industry. The U.S. Department of Transportation has the primary responsibility for regulating waste containers, transport vechicles, and other aspects of interstate transport of radioactive waste.

Existing NRC regulations for commercial LLW disposal in licensed disposal facilities are principally contained in a few paragraphs in 10 CFR Part 20 (§20.302). The requirements mainly describe in general terms the types of information to be included in an application for a disposal facility, and require that LLW disposal facilities must be sited on land owned by the state or federal government. In practice, this requirement has been met through lease conditions between the disposal facility operators and state landlords which provide that the states assume responsibility for long-term control and surveillance of the facility sites after closure.

Other NRC regulations--Part 30 ("Rules of General Applicability to Domestic Licensing of Byproduct Material"), Part 40 ("Domestic Licensing of Source Material"), and Part 70 ("Domestic Licensing of Special Nuclear Material")--apply to possession of licensed material by a disposal facility licensee. Part 2 ("Rules of Practice for Domestic Licensing Proceedings") contains general requirements for NRC licensing proceedings. Part 51 ("Licensing and Regulatory Policy and Procedures for Environmental Protection") contains requirements for compliance with the National Environmental Policy Act of 1969 (NEPA).

In discharging its responsibilities, NRC is empowered by the Atomic Energy Act to relinquish part of its regulatory authority over source, byproduct, and special nuclear material to the states. Under Section 274 of the Act, before the NRC enters into such an agreement, the state must have a radiation control program that is adequate to protect the public health and safety and compatible with NRC's program. Currently, there are 26 such Agreement States. Licensing of commercial LLW disposal facilities is part of the authority which may be relinquished by NRC to Agreement States. Of the six commercial disposal facilities which have operated in the United States, five of these facilities are located in Agreement States and are principally regulated by the Agreement States (See Table S.1).

To the extent that a new regulation such as Part 61 represents a change in NRC's radiation protection program for source, byproduct, and special nuclear material, it is necessary that the Agreement States cooperate in the formulation of compatible regulations and revise their existing regulations as necessary. Current NRC regulations regarding NRC's relationship with the Agreement States are contained in 10 CFR Part 150.

3. METHOD OF ANALYSIS

The overall method of analysis followed in this EIS may be summarized as follows:

1. First, the costs and impacts from the generation, transport, and disposal of waste at a reference near-surface disposal facility are calculated. This analysis is termed the "base case" analysis and represents the "no action alternative." The reference facility is sited and operated following existing practices and recommendations for siting and site operational safety. The base case facility, however, does not utilize some existing procedures commonly in effect at the real operating sites--e.g., the disposal of higher exposure rate packages on the bottom of disposal trenches. These assumptions were made to allow the calculation of a base level of costs and potential environmental impacts against which improvements (alternatives) could be evaluated with respect to their costs and effectiveness in mitigating impacts of the base case.

2. Second, a range of modifications and improvements (alternatives to the base case) are evaluated with respect to their incremental change in cost and effectiveness in mitigating potential impacts of the base case. The alternatives evaluated include those relating to various waste form, processing, and packaging options; near-surface disposal facility designs and operating procedures; site considerations; active institutional control time periods; and performance objectives. Alternatives were also considered and evaluated regarding financial assurance mechanisms for closure, postclosure care, and active institutional control, and the administrative procedures that should be followed in licensing near-surface disposal facilities.

3. Third, a comparative evaluation of the base case and alternatives is conducted which yields selection of the preferred performance objectives and technical requirements for the siting, design, operation, and long-term institutional control of a disposal facility. The performance objectives, technical, and other requirements developed through the analyses collectively form the basis for the new requirements to be codified through the Part 61 rulemaking action.

4. Finally, application of the preferred performance objectives and technical requirements selected and incorporated into Part 61 is evaluated to assess typical unmitigated impacts of LLW disposal following the preferred requirements. The disposal of waste according to the preferred requirements is analyzed on a regional basis at four regionally operated sites and the typical costs and impacts are determined. The analysis also helps assess the applicability of the Part 61 requirements to the wide range in site and waste characteristics expected in the regional disposal of LLW.

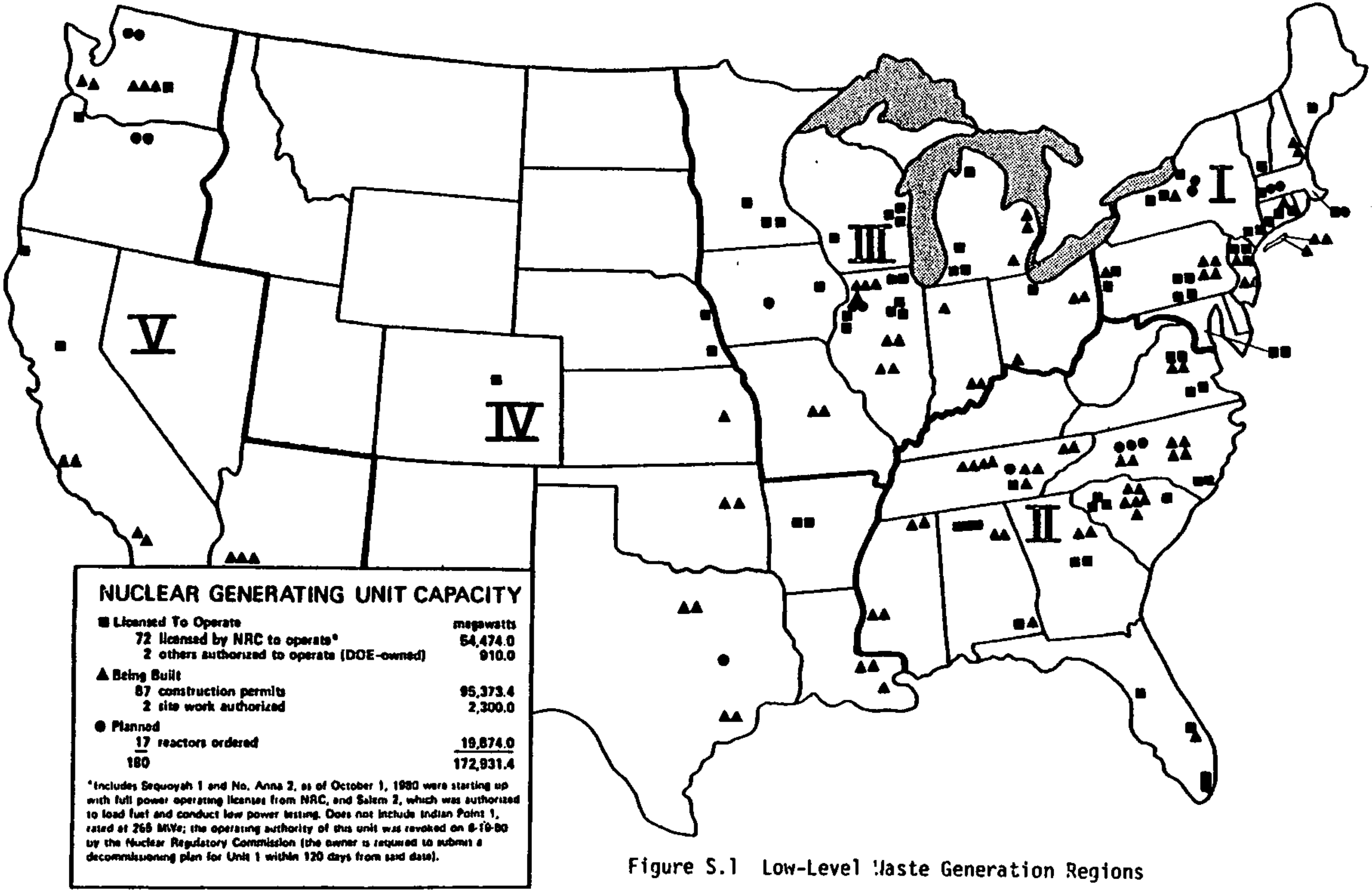
Information Base for Analysis

To perform these analyses, an information base had to be developed which involved three main components: alternative disposal facility environments, alternative waste characteristics, and alternative disposal facility designs and operating practices. Based upon this information base, an analysis methodology was developed to calculate impacts and compare alternatives.

First, the continental United States is assumed to be divided into four regions as shown in Figure S.1. The four regions considered correspond to the five U.S. Nuclear Regulatory Commission regions and are termed the northeast region (NRC Region I), the southeast region (NRC Region II), the midwest region (NRC Region III), and the western region (NRC Regions IV and V). In each region, a hypothetical regional disposal facility site is characterized. (The site in the western region is generally termed the southwest site.) These sites, while not representing any particular location within a region or any existing or possibly planned site, reflect typical environmental conditions within the regions. This allows consideration in the calculational methodology of a wide range of environmental conditions such as the amount of rainfall or the average distance from the waste generator to the disposal facility.

The next component of the information base involved considering and characterizing a wide range of waste types, waste forms, and processing options. In previous studies on LLW management and disposal, the disposed waste was usually assumed to be a mostly uncharacterized mass with little attempt to distinguish, in a quantitative manner, the different waste types and forms. In this EIS, however, LLW is separated into 36 waste streams and each waste stream is characterized in terms of its volumes and physical, chemical, and radiological properties as projected to be routinely generated during the period 1980 to 2000. The 36 waste streams so considered in this EIS are listed in Table S.2. Each waste stream represents a type of waste generated by a particular type of waste generator and having physical, chemical, radiological, and other characteristics unique to that individual stream. The most important radionuclides present in each waste stream are identified and the geometric mean of the range of activity concentrations for each radionuclide is determined from available data. The radionuclides considered are shown in Table S.3. The volumes of each waste stream are considered on a regional basis. That is, the volume of the waste stream is projected for each of the above four regions over the next 20 years, which allows consideration of regional impacts of management and disposal of LLW.

Furthermore, four generic alternative waste form and processing options are considered. These generic processing options, called "waste spectra," represent four relative levels of waste processing activities applied to the 36 waste streams characterized. The waste spectra have been developed to limit the number of waste form and packaging alternatives that would have to be analyzed, since an infinite number of possible combinations of various waste streams and processing options are available. The four spectra, which are described in detail in Appendix D, are as follows. Waste spectrum 1 characterizes existing and, in some cases, past waste management practices. Waste spectrum 2 characterizes improvements in the form of the waste through processing and reduction in waste



BECAUSE OF SPACE LIMITATIONS, SYMBOLS DO NOT REFLECT PRECISE LOCATIONS

Figure S.1 Low-Level Waste Generation Regions

Table S.2 Waste Streams Considered in Analyses

Waste Stream	Symbol
Group I: LWR Process Wastes	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartridges	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
Group II: Trash	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-NCTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS* Trash (large facilities)	N-SSTRASH
Industrial SS Trash (small facilities)	N+SSTRASH
Industrial Low Trash (large facilities)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
Group III: Low Specific Activity Wastes	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV** Waste (large facilities)	I-LIQSCVL
Institutional LSV Waste (small facilities)	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS Waste	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
Group IV: Special Wastes	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
Industrial High Activity Waste	N-NIGHACT

*SS: Source and Special Nuclear Material
**LSV: Liquid Scintillation Vial

Table S.3 Radionuclides Considered in Analyses

Isotope	Half Life (years)	Radiation Emitted	Principal Means Of Production
H-3	12.3	β	Fission; Li-6 (n, α)
C-14	5730	β	N-14 (n, p)
Fe-55	2.60	X	Fe-54 (n, γ)
Co-60	5.26	β, γ	Co-59 (n, γ)
Ni-59	80,000	X	Ni-58 (n, γ)
Ni-63	92	β	Ni-62 (n, γ)
Sr-90	28.1	β	Fission
Nb-94	20,000	β, γ	Nb-93 (n, γ)
Tc-99	2.12×10^5	β	Fission; Mo-98 (n, γ), Mo-99 (β^-)
I-129	1.17×10^7	β, γ	Fission
Cs-135	3.0×10^6	β	Fission; daughter Xe-135
Cs-137	30.0	β, γ	Fission
U-235	7.1×10^8	α, β, γ	Natural
U-238	4.51×10^9	α, γ	Natural
Np-237	2.14×10^6	α, β, γ	U-238 (n, 2n), U-237 (β^-)
Pu-238	86.4	α, γ	Np-237 (n, γ), Np-238 (β^-); daughter Cm-242
Pu-239	24,400	α, γ	U-238 (n, γ), U-239 (β^-), Np-239 (β^-)
Pu-240	6,580	α, γ	Multiple n-capture
Pu-241	13.2	α, β, γ	Multiple n-capture
Pu-242	2.79×10^5	α	Multiple n-capture; daughter Am-242
Am-241	458	α, γ	Daughter Pu-241
Am-243	7950	α, β, γ	Multiple n-capture
Cm-243	32	α, γ	Multiple n-capture
Cm-244	17.6	α, γ	Multiple n-capture

volume with relatively modest expenditures of time and money. These two spectra bound existing waste management practices, which are currently in a marked state of change due to state initiatives, a lack of disposal capacity, and economic considerations. In waste spectrum 1, for example, light water ion-exchange resins and filter sludges are shipped to disposal facilities in a dewatered form. Several other high activity waste streams are also shipped to disposal facilities in an unstable form, and no special effort is made to compact compressible waste streams. In waste spectrum 2, all light water reactor process wastes, including ion-exchange resins and filter sludges, are stabilized by solidification while other high activity waste streams are stabilized through improved packaging techniques. All compactible trash streams are compacted. Waste spectrum 3 characterizes further waste form improvements and volume reduction at further increased costs, including incineration of most combustible waste streams. Waste spectrum 4 characterizes the maximum volume reduction and improved waste forms that can currently be practically achieved.

The third component of the information base involved characterizing (costs, operational exposures, etc.) a number of alternative disposal facility designs and operating practices. These alternatives are developed in Appendix F to the main text, and include alternatives which will reduce potential impacts to inadvertent intruders, reduce ground-water migration and long-term social impacts, improve operational safety, or combinations thereof. The alternatives characterized include the following:

Deeper trenches	Improved monitoring
Thicker trench covers	Moisture barriers
Increased backfill thickness	Sand backfill
Layered waste disposal	Improved surface water drainage
Slit trenches	Weather shielding
Caisson disposal	Stacked waste emplacement
Concrete walled trenches	Waste segregation
Grouting	Decontainerized disposal
Engineered intruder barriers	Dynamic compaction
Improved compaction	

Other disposal alternatives were also briefly examined. These included potential land based methods (intermediate depth disposal, mined cavities) as well as other potential disposal methods (ocean disposal, space disposal).

Use of Reference Waste Volume and Disposal Facility

From the above, it can be seen that when considering the effect of alternative regional, waste form, and facilty design and operation characteristics on the magnitude of the impact measures calculated, an extremely large number (thousands) of possible permutations can be considered. To enable development of performance objectives and technical requirements for LLW disposal, the number of these permutations needed to be controlled and analyzed on a systematic basis. NRC, therefore, adopted use of (1) a reference waste volume distribution and (2) a reference disposal facility site and design.

As discussed in Appendix D, the reference waste volume distribution is generated through averaging all the waste volumes assumed to be generated in each of the 36 streams for each of the four regions, and normalizing these volumes to one million m^3 of waste for waste spectrum one. This allows the effects of alternative waste spectra and alternative disposal facility designs and operating practices to be compared on a common basis.

To help provide conservative bounds to the potential costs and impacts of waste disposal, the reference LLW disposal facility is assumed to be sited in a humid eastern environment. NRC staff anticipates that over the next 20 years, over three-quarters of the waste generated in the United States will be generated in humid environments--i.e., in the eastern and humid midwestern sections of the country. Regional disposal of waste therefore implies that most of the waste generated in humid environments would also be disposed in humid environments. Potential ground-water impacts (and actions required to protect ground water) at a humid site are generally expected to be greater than those at an arid area. For this EIS, the reference disposal facility is assumed to have environmental characteristics corresponding to the southeast regional site, although either the northeast regional site or the midwest regional site could have been used for this purpose.

The reference facility is sized to accept a relatively large quantity of waste--i.e., 50,000 m^3 of waste per year over a 20-year operating life, or a total volume of one million m^3. This corresponds to approximately one-quarter of the total volume of LLW projected in the United States to the year 2000. Disposal of one million m^3 of waste in the reference facility will require about 150 acres of land, which corresponds to an approximate upper bound of the land area of current commercial disposal facilities.

The reference facility site minimally meets all of the site suitability requirements set out in Chapter 5. The facility is also assumed to be operated in compliance with minimum radiation safety practices required by provisions of 10 CFR Part 20. Although the facility is assumed to comply with the NRC Branch Technical Position on Site Closure and Stabilization (Appendix I), no special effort is assumed regarding the waste form or design and operational practices to ensure long-term site stability. Several design and operational improvements directed at stability that have been instituted at some existing sites have not been assumed for the base case site (e.g., vibratory compaction of backfill material). This has been done to establish a base case level of long-term costs and radiological impacts against which measures to improve site performance, achieve greater site stability, minimize radiological impacts, and to ensure adequate funding can be assessed. The facility is described in detail in Appendix E. A brief description follows.

The disposal facility is assumed to be operated for profit by a small corporation which is engaged in other nuclear-related business activities in addition to operating the disposal facility. The disposal area at the reference facility includes 58 disposal trenches with dimensions of 180 m (591 ft) long, 30 m (100 ft) wide, and 8 m (26 ft) deep. The rather large trench sizes assumed are representative of recent trends at existing disposal sites. Support facilities and structures at the site include (1) an administration building, (2) a health physics/security building, (3) a warehouse, (4) a garage, (5) a waste activities building, and (6) a storage shed. All structures at the site are one-story metallic structures on concrete pad foundations.

Shipments of radioactive waste arrive by truck and are processed onto the site on a first-come, first-served basis. Accompanying the shipments are manifest documents--termed radioactive shipment records (RSRs)--which describe the content of the shipment. Arriving shipments are inspected for compliance with applicable federal regulations and waste acceptance criteria established as conditions in the disposal facility license.

Waste is randomly emplaced in the trench, sometimes using cranes and forklifts, and backfilled with dirt removed during trench excavation. Random waste emplacement results in a trench volume use efficiency of about 50 percent. Waste is emplaced to within one meter of the top of the trench. Earthen fill is then backfilled into the trench until the trench cover approximately corresponds to the original grade of the site surface. A one-meter thick earthen cap is then placed upon the backfill and is mounded. The earthen cap is then covered with natural overburden material as necessary to provide good drainage characteristics and according to the final contours planned for the site surface. The overburden is then reseeded to promote growth of a short-rooted grass cover.

After a 20-year operating period, closure (decommissioning) of the facility is assumed to require approximately one to two years and involves dismantling and decontamination of site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring. The licensee also makes a final survey of the disposal area to make sure direct radiation levels are at essentially background levels. Following closure, the disposal license is terminated and control of the site is transferred to the site owner. For this EIS, the site owner is assumed to be a state agency which carries out an active institutional control program of surveillance, monitoring, and maintenance for 100 years.

Impact Measures

The impact measures considered in this EIS include short-term radiological exposures, long-term radiological exposures, costs, energy use, and land use. These impact measures are listed in Table S.4.

Of these, the principal impact measures considered involved long-term radiological exposures and costs. Long-term radiological exposures could involve activities such as man potentially contacting the waste after disposal (i.e., inadvertent human intrusion into the disposal facility), potential leaching and transport of the waste through the ground water; intrusion and dispersion by plants and animals; long-term erosion of the site with eventual uncovering of the waste and surface

Table S.4 Impact Measures Used in Analyses

Waste Management Phase	Impact Measure
Waste processing	Costs Energy use Occupational exposures due to waste processing Population exposures due to waste incineration
Waste transportation	Costs Energy use Occupational exposures Population exposures
Waste disposal	Costs Energy use Land use Occupational exposures Exposures to individuals and populations due to: o operational accidents o ground-water migration o inadvertent human intrusion

water and air transport; and release of gaseous decomposition products from the waste containing radioactive species (e.g., tritiated methane gas). Further discussion is provided below:

Human Intrusion Exposure Pathways. Intrusion into disposed waste may be either deliberate or inadvertent. A deliberate intrusion event implies that the intruder knows of the potential hazard of the disposed waste but for some reason deliberately chooses to ignore the hazard. (For example, the intruder could be seeking something of possible value in the disposed waste.) NRC believes that deliberate intrusion into the disposal facility cannot reasonably be protected against, and it is not considered further. After the facility closes, however, and after active institutional control and surveillance over the facility have been removed, one or a few individuals could inadvertently disturb waste at the disposal facility through such activities as constructing a house or through gardening. In this case the intruder is unaware of the presence of the waste.

Intrusion into a closed waste disposal facility, assuming a breakdown in institutional controls, has been examined in detail in studies by a number of industry, national laboratory, and federal agency contractor investigators (see Section 4.2.1 of Chapter 4). These studies analyzed a range of intrusion exposure pathways ranging from potentially trivial events to events which could cause relatively significant exposures.

Based on a review of the pathways considered by these investigators, NRC selected a limited number for analysis in the EIS. The events are conservatively assumed to occur based upon consideration of typical human activities. NRC recognizes the hypothetical nature of such events and that they may never occur. Given their hypothetical nature, NRC has assumed reasonably conservative (but not overly conservative) actions on the part of the intruder. In addition, some judgment was also made as to the likelihood and extent of the events occurring depending upon specific waste forms and disposal practices.

Two concentration-limited events and one activity-limited event are analyzed. One involves the assumed construction of a house directly on the disposal facility and is referred to as the intruder-construction scenario. A modification of this scenario, termed the intruder-discovery scenario, is assumed to occur when the inadvertent intruder contacts solid remains of waste, realizes that something is wrong and ceases intrusion activities. The second event involves an individual or several individuals living in the house thus constructed and is referred to as the intruder-agriculture scenario. The activity-limited event, which involves consumption of water by the intruder from a well drilled at the site, is termed the intruder-well scenario. (See following section on ground-water migration.) In addition, potential population exposures from radioactive material dispersed by the inadvertent intruder are also analyzed.

Ground-Water Migration. Potential impacts due to long-term releases to ground water are given major consideration in this EIS. Ground-water impacts are calculated for four human access locations: (1) a well located onsite which is assumed to be used by a potential inadvertent intruder following the end of the active institutional control period; (2) a well located at the site boundary which is assumed to be used by a few individuals; (3) a well assumed to be located approximately 500 meters downgradient from the disposal facility and used by a small population of about 100 persons; and (4) a small stream located about one kilometer downgradient of the disposal facility and assumed to be used by a small population of about 300 persons. All exposures listed are to individuals.

Possible increases in percolation into disposal cells due to intrusion by humans, burrowing animals, deep-rooted plants, or other factors are incorporated into the analyses.

Other Long-Term Release Pathways. There may be other potential pathways for long-term release of radionuclides to the environment from disposed waste. These pathways include:

- Gaseous releases from decomposing waste;
- Plant and animal intrusion; and
- Wind and surface water erosion and transport.

NRC staff believes, however, that the most significant pathway is ground-water migration. Gaseous releases do not have a large impact and can be reduced by assuring stable site conditions. Impacts from plant and animal intrusion are site-specific and can be reduced through engineering designs applied to reduce ground-water migration and potential intruder exposures. Erosion is a slow, long-term process which can be controlled through proper siting and good operational techniques.

Costs. Costs are calculated over 20 years operation of the disposal facility and are separated in this EIS into three components:

- processing costs
- transportation costs
- disposal facility costs.

Waste processing costs include costs associated with processing (e.g., compaction, solidification) and packaging wastes prior to disposal. Processing costs are separated into those associated with processing by waste generators and those which could result from transfer of the waste to a centralized regional processing center prior to disposal. Transportation costs are costs associated with transferring the waste to the disposal facility and for the reference facility, are calculated based upon an average transport distance of 400 miles.

Disposal facility costs are separated into (1) design and operating costs and (2) postoperational costs. Design and operating costs are those costs associated with siting, designing, constructing, and operating the facility over 20 years. These costs may be further separated into capital and operational costs (see Appendix Q), and are a function of the alternative disposal facility designs considered in the EIS. Postoperational costs are divided into closure costs and institutional control (long-term care) costs. Closure costs are calculated assuming that adequate funds for closure are provided for by the licensee through use of an investment fund (represented as a surcharge on received waste). The availability of funds for closure is assumed to be assured by a mechanism such as a surety bond. Institutional control costs are calculated based on the assumption that a state-operated sinking fund is established and that a surcharge is levied upon the waste received at the disposal facility on a cost-per-waste-volume arrangement. All postoperational costs are calculated as costs to a disposal facility customer.

4. COSTS AND IMPACTS OF BASE CASE (NO ACTION ALTERNATIVE)

Principal long-term radiological impacts for the base case (no action) alternative are listed in Table S.5 for several time periods following license termination.

Direct impacts to a potential inadvertent intruder (in mrem/yr to an individual) are summed over all 23 radionuclides considered in the analysis and volume-averaged over all 36 waste streams disposed into the disposal facility. The highest potential intruder exposures are those to the bone. Whole body exposures are also shown. Over the first 500 years, potential exposures to the bone from the intruder-construction scenario drop by a factor of 3 from

Table S.5 Principal Long-Term Radiological Impacts for the Base Case (No Action) Alternative

	Costs and Impacts	
Direct intruder impacts:		
Body (mrem/yr)*		
o 100 C	1.502E+3**	
A	1.769E+3	
o 500 C	7.808E+1	
A	4.336E+1	
o 2000 C	4.491E+1	
A	2.251E+1	
Bone (mrem/yr)		
o 100 C	3.095E+3	
A	2.482E+3	
o 500 C	1.183E+3	
A	4.851E+2	
o 2000 C	8.264E+2	
A	3.347E+2	
Offsite releases from intrusion (at 100 years):		
Airborne impacts (man-millirem/yr)		
o Body	2.242E+3	
o Bone	4.060E+4	
Waterborne impacts (millirem/yr)		
o Body	8.475E-2	
o Bone	5.097E-1	
Ground-water impacts: (mrem/yr)		
Body		
o Intruder well	3.044E+1	(100)***
o Boundary well	1.571E+2	(70)
o Population well	4.434E-1	(6,000)
o Surface stream	1.781E-2	(8,000)
Bone		
o Intruder well	3.063E+0	(6,000)
o Boundary well	3.061E+0	(6,000)
o Population well	6.197E-1	(8,000)
o Surface Stream	2.685E-2	(10,000)
Thyroid		
o Intruder well	8.462E+2	(4,000)
o Boundary well	8.462E+2	(4,000)
o Population well	2.673E+2	(4,000)
o Surface stream	1.218E+1	(4,000)

*C = Intruder-Construction Scenario
A = Intruder-Agriculture Scenario
**The notation 1.502E+3 means 1.502×10^3.
***The numbers in parentheses indicate the approximate time in years following facility closure that maximum impacts occur.

about 3 rems/yr to about one rem/yr. Over the next 1500 years, however, potential exposures are reasonably constant, and are still at about 800 mrem/yr at 2000 years. A similar pattern is observed for potential exposure to the whole body. The potential exposures were conservatively calculated giving no credit (with the exception of activated metal) for the ability of waste form to reduce airborne dispersion of radionuclides or uptake by plant roots. That is, the waste is assumed to behave and disperse in a manner similar to ordinary dirt.

Ground-water exposures are also calculated in a conservative manner and are high for the base case. Due to the readily degradable nature of much of the waste and assumed inadequate site operational practices, severe slumping and subsidence problems occur. The disposal area is assumed to be characterized by potholes and subsidence depressions, leading to concentrated sources of rainwater infiltration. Maximum annual doses to all organs, with the exception of the thyroid and bone, are about 30 millirem at the intruder well, exceed 150 mrem at the boundary well, are on the order of 0.1 mrem at the population well, and are on the order of 10^{-2} to 10^{-3} mrem at the surface body water. Maximum annual thyroid doses are in the range of 850 mrem at the intruder and population wells, 270 mrem at the population well, and 12 mrem at the surface water body. It is not likely that doses to actual individuals could ever be this high, notwithstanding the conservatism of the analysis. For one thing, potholes and depressions would be filled in by the site owner, thus reducing the percolation. In addition, ground-water movement of radionuclides would almost certainly be detected through monitoring wells long before appreciable exposures could be received by the public. A more important point is that a considerable amount of effort and cost to the site owner may be required to prevent such exposures from occurring.

This is evidenced by the size of the postoperational funds that would have to be collected during the 20-year site operational period--i.e., \$38.2 million, or about \$38/m^3 assuming 1 million m^3 of waste (\$1.08/ft^3). These costs are shown in Table S.6 and are calculated assuming a high level of long-term maintenance in a site having moderately permeable soils. For sites having very impermeable soils where there is a possibility of a major leachate pumping and treatment problem (such as the current situation at the Maxey Flats, Kentucky disposal facility), then the amount of postoperational funds that would have to be collected is estimated to be \$50 million (\$1.42/ft^3).

NRC believes that this level of long-term maintenance and costs is unacceptably high. There is considerable uncertainty in the calculated long-term costs and the costs could easily be higher. Leaving a disposal facility in a condition so that extensive active maintenance activities are required to ensure public health and safety could result in a considerable financial burden to the site owner and to future generations. It is important to realize that these costs were calculated assuming that funds are collected as a surcharge on received waste and placed into a state-operated sinking fund (at an average interest rate of 10% and an average inflation rate of 9%). However, the facility may close prematurely and prior to collection of sufficient funds. The loss in accrued interest could be significant. For example, a major leachate pumping

Table S.6 Other Impacts and Costs of the Base Case (No Action) Alternative

	Costs and Impacts*
Short-term population exposures (man-mrem):	
Processing by waste generator**	-
Processing at regional processing center**	-
Waste transportation	7.12E+5
Short-term occupational exposures (man-mrem):	
Processing by waste generator**	-
Processing at regional processing center**	-
Waste transportation	6.89E+6
Waste disposal	3.05E+6
Waste generation and transport costs: ($)	
Processing by waste generator**	-
Processing at regional processing center**	-
Waste transportation	2.49E+8
Disposal costs: ($)	
Design and op.	1.85E+8
Postoperational	3.82E+7
Total	2.23E+8
Unit ($/$m^3$)	223
Incremental energy use: (gal)**	--
Land use: (m^2)	3.47E+5
Waste volume disposed: (m^3)	1.00E+6
Total volume not acceptable: (m^3)	0

*Costs and impacts are total costs and impacts over the 20-year operating life of the disposal facility.
**Not calculated for the base case (see text for explanation).

and treatment program is estimated to cost about $1 million per year in 1980 dollars. By the year 2000 and assuming a 9% interest rate over 20 years, this leachate pumping and treatment program would cost between five and six million dollars. The site owner could easily be saddled with expenditures of several million dollars per year for several years.

Another problem is that a high level of long-term maintenance implies that one is depending upon extensive human actions possibly carried out several years in the future in order to ensure public health and safety, and there is no assurance that such extensive activities would actually be carried out. For example, a seemingly minor to moderate water accumulation problem could be potentially ignored (perhaps for the sake of economics) until a major expensive problem develops. In addition, extensive site maintenance activities can lead to releases of quantities of radionuclides offsite and subsequent human exposures.

Other base case costs and impacts are also summarized in Table S.6. The costs and impacts are calculated over 20 years of waste generation, processing, transport, and disposal. Included are population exposures from waste processing and transportation; occupational exposures for waste processing, transportation, and disposal; costs for waste processing and transportation; incremental energy use for processing, transportation, and disposal; land used for disposal; and total waste volume disposed of. Impact measures for energy use as well as occupational exposures, costs, and population exposures for waste processing are not calculated for the base case and are not shown in Table S.6. Rather, incremental changes in these impact measures associated with alternative disposal facility design options and additional waste processing of specific waste streams are calculated. This is explained in greater detail in Section 4.3.2 of Chapter 4 and in Appendices D and G.

In summary, Tables S.5 and S.6 establish a baseline of cost and impact data, and furthermore demonstrate a need for regulatory action. The data shows that inadvertent intruder exposures are relatively high at 100 years, at which point they begin to decrease, leveling off at around 400-500 years. Although the exposures to the inadvertent intruder are not so high as to cause great (immediate life-threatening) concern for the one or few individuals who might be exposed, some additional controls could be exercised that could reduce such potential exposures to lower levels during the 100 to 500-year time frame. Furthermore, the major portion of the exposures may be contributed by a few waste streams that could be controlled to reduce potential exposures. The same would apply to exposures from consumption of ground water at various locations. Finally, the unstable site conditions for the base case results in a very high level of long-term maintenance and costs to the site owner, and a corresponding high level of long-term social commitment.

5. ANALYSIS OF ALTERNATIVES--DEVELOPMENT OF PERFORMANCE OBJECTIVES AND TECHNICAL CRITERIA

5.1 Performance Objectives

As a part of the analyses, NRC analyzed a range of alternative performance objectives to assure an adequate level of protection for the inadvertent intruder and long-term social and environmental protection. As previously discussed there are four basic performance objectives that should be achieved in disposal:

1. Protect the inadvertent intruder;

2. Assure long-term stability to eliminate the need for long-term maintenance after operations cease;

3. Protect public health and safety (and the environment) over the long term; and

4. Assure safety during the short-term operational phase.

The results of the analyses to arrive at preferred performance objectives are presented below.

5.1.1 Protection of the Inadvertent Intruder

The impacts for potential inadvertent intrusion, while not immediately life-threatening, are significant since impacts on the order of several hundred mrem/yr could last for long time periods. Four methods were addressed by which potential human intrusion impacts may be mitigated:

1. Controlling the disposal of specific waste streams;

2. Waste form and packaging;

3. Use of engineered and/or natural barriers to intrusion; and

4. Institutional controls.

Controlling the Disposal of Specific Waste Streams

In the analysis, the potential hazard to an inadvertent intruder is initially principally due to gamma radiation from fission products such as Cs-137, and averages at about 1.5 to 3 rems/yr at 100 years following license termination. Due to radioactive decay, however, the potential hazard quickly drops to about 1000 mrem/yr to bone at about 500 years following facility closure and about 800 mrem/yr to bone at about 2,000 years following facility closure. Most of the longer-term hazard is caused by two small volume waste streams (1.94 E+4 m^3) containing large quantities of transuranic isotopes. If these waste streams are eliminated from the analysis (that is, if transuranics in large quantities are eliminated from near-surface disposal), potential long-term impacts averaged over the remaining 34 waste streams are only a few mrem/yr (e.g., 3 to 5) after 500 years.

Thus, it appears that by eliminating waste streams containing large quantities of transuranics from near-surface disposal, the long-term hazard to a potential inadvertent intruder may be greatly reduced. Over the short term, however, even with the removal of the transuranic streams, potential impacts can be significant--e.g., about 1.5 rems/yr. It is useful to consider ways in which the near-term impacts may be reduced. As discussed below, this could result from more restrictive near-surface disposal requirements for a few higher-active waste streams.

Waste Form and Packaging

Another way in which potential intruder exposures can be reduced is through improvements in waste form and packaging, as well as minor improvements in site operational practices. These improvements can lead to reduced exposures in two principal ways:

1. The likelihood that the intruder will stay in contact with the waste (e.g., construct in it, grow crops in it) is reduced if the waste is placed into a stable form or package and disposed in a segregated manner from unstable wastes; and

2. The potential for the waste to be dispersed into a form which can be readily inhaled or taken up by plant roots is reduced if the waste is placed into a stable form or package.

Potential inadvertent intruder hazards were calculated for the base case based upon an assumption that all waste streams are randomly mixed together during disposal. Due to the slumping, subsidence, and higher infiltration that would be associated with this disposal practice, rapid waste degradation could occur. Even wastes that have been placed into a stable form or package could be subject to such rapid decomposition. However, if the stable wastes were also segregated and disposed of in separate disposal cells so that waste degradation would be minimized, then the likelihood that inadvertent intrusion would lead to prolonged contact with the stable wastes would be greatly reduced. It is not credible to suppose that such activities as housing construction or gardening could take place under these conditions since the inadvertent intruder would contact hunks of waste and realize something is wrong. Potential exposures would be limited to those received during discovery of the waste. If high activity waste streams are stabilized and segregated from compressible waste streams, exposures to an inadvertent intruder averaged over all waste streams would be reduced at 100 years following closure from 1 to 3 rems/yr to less than 100 mrem/yr.

In addition, if the waste is contacted through inadvertent intrusion, then potential inhalation exposures would be reduced if the waste is in a stable, less dispersible waste form. Similarly, exposure pathways which occur through consumption would be reduced if the waste is placed into a low leaching form. In order for radionuclides to be taken up by plants, the radionuclides must first be dissolved and leached out of the waste.

Another question addressed is how long waste form may be relied upon to reduce intruder impacts. As a minimum, the waste form should last through the operating life of the disposal facility, the closure period, any observation period prior to the termination of the facility license, and the active institutional control period. This results in a requirement of waste stability for at least 150 years. This requirement should be readily achievable, since if the disposal cell is stabilized so that minimum infiltration is introduced to the disposal cell, then the waste form should be effective against intrusion for several hundred years. It is not reasonable, however, to expect this to be the case indefinitely. After several hundred years (i.e., on the order of 500 years), most of the shorter-lived radionuclides will have decayed away, leaving the longer-lived radionuclides. The reduction in hazard after 500 years takes place at a much slower rate. It would appear, then, that for most wastes, a limit of 500 years would appear to be the maximum reasonable upper bound. Attempting to reduce intruder impacts through waste form beyond 500 years would really not accomplish much in the way of additional protection.

Use of Engineered and/or Natural Barriers to Intrusion

Another method by which the hazard to a potential intruder may be reduced is to dispose of the waste in a manner that would make it more difficult for a potential intruder to contact the waste--that is, by placing one or more natural or engineered barriers between the waste and the intruder. The majority of the waste streams that could require disposal by methods that provide protection against inadvertent intrusion would probably also be characterized by high surface radiation levels.

NRC analyzed a number of such potential barriers to an intruder and these are described in detail in Appendix F and Chapter 4. The barriers considered and additional facility costs associated with use of these barriers are shown in Table S.7. These costs are for facility design and operation and do not include costs for closure and long-term care. In general, the barriers can be grouped into three major categories as follows:

1. Engineered barriers, including grouting or "engineered structures" such as caissons or concrete-walled trenches;

2. Depth of disposal, including thicker trench caps, layered waste disposal, and slit trenches; and

3. Other methods of disposal, including intermediate depth burial, mined cavities, ocean disposal, and space disposal.

Most waste streams contain relatively low levels of activity while some contain relatively high levels of activity. It would not appear to be justified to require that all waste streams would require disposal using a barrier to an intruder. For most waste streams, the potential hazard falls off rapidly with time--e.g., to levels on the order of a few millirems or less after a few hundred years. Thus, the use of such barriers would only be required for the higher activity waste streams. This can be provided in a relatively inexpensive manner through techniques such as layering. Layering refers to the technique of placing higher activity waste streams at the bottom of the disposal cell so that there is at least 5 meters of earth or lower activity waste between the top of the higher activity waste and the surface of the earth. Using this technique, waste volume-averaged intruder exposures can be reduced (at 100 years following site closure) to the range of 70-80 mrem/yr. If higher activity waste streams are stabilized and segregated from compressible wastes, volume-averaged exposures at this time period are reduced to exposures in the range of 30 mrem/yr.

Table S.7 Summary of Incremental Barrier Costs For Facility Design and Operation

Type of Barrier	Additional Disposal Costs $/m^3	$/ft^3	
No barrier	0	0	*
Thicker cap - 3m of soil	1.59	0.05	*
Thicker cap - 3m of compacted clay	10.89	0.31	*
Layered waste disposal	37.73	1.07	**
Slit trench (10% of waste)	91.49	2.59	**
Caisson disposal (10% of waste)	216.45	6.13	**
Walled trench (10% of waste)	256.09	7.25	**
Walled trench (100% of waste)	160.99	4.56	*
Grouting--cement†	60.46	1.71	*
Grouting--low-strength cement†	46.86	1.33	*
Engineered intruder barrier	59.17	1.68	*
Intermediate depth burial	53-159	1.50-4.50	*
Mined cavity	327-654	9.26-18.52	*
Ocean disposal	710-2200	20.11-62.31	*
Space disposal	2,000,000	56,600	*

*Unit costs based upon 1,000,000 m^3 of waste disposed.

**Unit costs based upon volume of waste disposed by the disposal method indicated. For this table, the costs are based upon a volume of about 100,000 m^3.

†Unit costs include additional costs for stacked waste emplacement.

A time limitation on the effectiveness of natural and engineered barriers was also considered. From the analyses performed for this EIS, it was determined that due to radioactive decay, exposures to a potential inadvertent intruder from almost all waste streams typically considered to be LLW fall to a few millirems after a few hundred years--e.g., 500 years. After 500 years, only a few waste streams are estimated to result in annual potential intruder exposures of a few hundred millirems. Very few (e.g., one or two) streams having small volumes are estimated to result in potential intruder exposures exceeding 500 mrem/yr after 500 years.

On the other hand, waste streams that are generally considered to be "high-level waste" (e.g., spent reactor fuel, solidified first solvent extraction stages from a nuclear fuel reprocessing plant) contain much higher initial levels of radioactivity. Typically, the potential hazard from high-level waste disposal is dominated by fission products over approximately the first 600 years. After that approximate time period, most of the fission-product activity has decayed, except for iodine-129 and technetium-99; radioactivity is dominated thereafter by the actinides--e.g., U, Np, Pu, Am, Cm and their daughters. Wastes which still contain appreciable activity after several hundred years (e.g., 500 years) would appear to more closely resemble high-level waste than what is usually considered to be low-level waste.

Finally, limitations on the effectiveness of barriers to a potential inadvertent intruder was discussed at the regional workshops on the Part 61 regulation. At these workshops, there appeared to be general agreement that a time period of 500 years seemed appropriate for most easy-to-implement intruder barriers.

Institutional Controls

Another mechanism for reducing potential impacts to a potential inadvertent intruder is use of institutional controls. Institutional controls are controls which require performance of some action by a government agency to preclude human contact with the waste, or require a continuing social order. Examples include controlled access to the site, controlled productive use of the site (e.g., as a golf course), and periodic inspection and surveillance. Ultimately, institutional controls must also rely upon relatively passive means involving some manner of social order. Probably the most significant concepts for long-term passive institutional control measures are those of control of the land by a governmental organization, land-use restrictions in the form of titles or deeds, and multiplicity of records.

Given this, however, it is still appropriate to consider how long institutional controls may be expected to preclude intrusion. Markers and monuments established at a disposal site may be stolen or defaced, and the nature of the hazard may be buried in forgotten governmental files. Land-use restrictions may be potentially ignored, or a future government bureaucracy may simply mistakenly release a site for inappropriate use.

The maximum time period for which active institutional controls can be relied upon to preclude inadvertent intrusion has been investigated by a number of people, including EPA as well as a number of researchers doing work on establishing a waste classification system. EPA has proposed that a limit of 100 years should be used as a limit for the length of institutional controls. This limit was proposed based upon consideration of public input received at a number of public forums on radioactive waste disposal held by EPA. In various studies exploring ways in which to classify radioactive waste for disposal, different institutional control periods have been used. The institutional control periods assumed in these studies were all less than a few hundreds of years and ranged in these studies from 100 to 200 years.

The maximum time period that should be assumed for active institutional controls was discussed at a series of four regional workshops held on the preliminary draft of the Part 61 rule. The general consensus of these workshops was that a 100-year limit for active institutional controls was appropriate.

Development of Preferred Performance Objectives

Based upon the analyses and discussion of the previous subsections, the following conclusions were reached:

1. The potential for inadvertent human intrusion into a closed disposal facility at some point after closure of the disposal facility is likely. Extensive intrusion activities such as major housing or apartment construction are unlikely. The potential exposures from inadvertent intrusion are relatively high for the first few 100 years (i.e., 1.5-3 rems/year at 100 years) but, provided that a few waste streams are removed, then drop to a low level (a few mrem/year) after about 500 years.

2. Some waste streams present relatively little hazard to an inadvertent intruder. Some present an initial high potential hazard. If inadvertent intruders can be protected against contacting these latter waste streams for a few hundred years, then such waste streams present much reduced potential hazards. Such protection may be achieved through use of natural and engineered barriers to intrusion. However, there is a limit (e.g., 500 years) as to how long such barriers can be expected to last. Some waste streams may not be acceptable for near-surface disposal.

3. The extent and consequences of potential inadvertent intrusion are related to waste form and disposal facility design and operating practices. For example, improved waste form and packaging can reduce potential exposures through inhalation and food consumption pathways. Volume reduction may increase exposures from direct gamma radiation. If the waste is in a structually stable form and segregated from other wastes, then as long as the structural stability is retained, the possibility of extensive inadvertent intrusion activities is not considered credible.

4. Institutional controls can be effective in reducing the potential for inadvertent intrusion and in reducing potential intruder exposures.

Two aspects were then analyzed in further detail and specific limits developed to determine the disposal requirements of different LLW streams based on protection of an inadvertent intruder--that is, to determine which streams may be acceptable for near-surface disposal, which streams may require barriers to an intruder, and which streams may be generally unacceptable for near-surface disposal. The aspects that were developed included:

1. An exposure guideline defining an acceptable level of safety regarding protection of an inadvertent intruder which can be used to stipulate when controls against potential intrusion should be implemented; and

2. A maximum time during which active institutional controls can be relied on to prevent inadvertent intrusion.

Three alternative dose rate limits were examined quantitatively in this EIS for protection of an inadvertent intruder:

- o 25 mrem/yr to the whole body;
- o 500 mrem/yr to the whole body; and
- o 5000 mrem/yr (5 rem/yr) to the whole body.

Four alternative active institutional control periods were also analyzed:

- o 50 years
- o 100 years
- o 150 years
- o 300 years

These alternatives were examined in a case study set out in Chapter 4 of this EIS. The results of this case study are too lengthy to include here but resulted in the selection of a 500 mrem/yr (whole body) dose rate guideline for protection of an inadvertent intruder and a 100-year assumed maximum active institutional control period.

The preferred dose limitation criteria objective selected by NRC is similar to the maximum permissible levels of radiation in unrestricted areas as set out in 10 CFR Part 20. A dose rate limit in the range of 25 mrem/year was judged to result in considerably more costs, more change in existing practices, and greater reduction in disposal efficiency than the other two alternatives. This is especially important considering the hypothetical nature of the intrusion event. The 5 rem/yr alternative was seen to involve approximately the same costs and impacts as the 500 mrem/yr alternative. The higher dose rate limit, however, could potentially allow disposal of larger quantities of long-lived isotopes, which could result in moderately higher intruder hazards which could extend for long time periods. Therefore, 500 mrem/yr (whole body) was selected as a general dose rate limitation guideline. This limitation agrees with the consensus of the four regional workshops.

The second question was how long should credit be given to active institutional controls to prevent such intrusion. A time period that is too short could result in very high disposal costs for much of the LLW. A period that is very long, on the other hand, may place an undue burden on future generations. NRC analyzed alternative institutional control periods of 50, 100, 150, and 300 years to see if there was any technical preference for selecting one time period over another. From the analysis, there did not appear to be any overly compelling numerical reason to adopt a particular institutional control period. NRC believes, however, that institutional controls will last at least 50 years.

Three-hundred years appeared to be too long of a time period and did not offer any compelling numerical advantage over 150 years. The preferred alternative was, therefore, in the range of 100 to 150 years. NRC selected 100 years as the preferred institutional control period. This period of time agrees with previous estimates on the effective length of active institutional controls made by EPA and also is consistent with the consensus of the regional workshops. Based on the comments received on the preliminary draft of Part 61 and at the workshops, NRC identified no overriding social or political rationale for selection of one time period over another. The general consensus was that 100 years was about the right time period upon which reliance should be placed on active institutional controls.

5.1.2 Long-Term Environmental Protection

In developing performance objectives, NRC considered two key aspects related to long-term environmental protection: long-term potential exposure pathways, and long-term site stability.

The potential exposure pathways included: (1) ground-water migration, (2) gaseous releases from decomposing waste, (3) plant and animal intrusion, and (4) wind and surface water erosion and transport. Of the pathways, the consumption and use of water containing radionuclides from disposed waste is believed to be the most significant long-term environmental release pathway of potential human exposure. Thus, NRC concentrated on analysis of ground-water impacts in development of the performance objective.

In the analysis, it became apparent that long-term ground-water migration cannot be analyzed by only considering potential radiological impacts. Site stability and the need for long-term social commitment to care for sites over the long term and to maintain potential radiological impacts to low levels must also be considered as an integral part of the analysis.

The unpredictable nature of waste/disposal site instability can lead to increased radiological and economic impacts at both humid and arid sites. At humid sites, stable disposal cell covers are needed to minimize water infiltration into the waste and thus maintain potential ground-water releases to levels as low as reasonably achievable. Waste instability in poorly drained soils can especially lead to a potential "bathtub" problem, which can further lead to costly long-term trench pumping and site stabilization programs. In arid sites, trench instability can lead to subsidence and increased plant and animal intrusion plus increased potential for wind erosion and dispersion of trench contents.

Three interrelated factors contribute to waste form/disposal site instability, the contact of water with waste, and the resulting long-term radiological and economic consequences:

- site environment;
- site design and operations; and
- waste form.

To consider the maximum potential impacts from waste disposal, the base case site analyzed was a humid site, although as stated above, waste/site instability is also important at arid sites. Variations to site designs and operating practices can lead to greater site stability and minimize long-term migration. Some of these variations considered in the EIS include: (1) segregation of compressible wastes and wastes containing large quantities of organic chemicals or chelating agents, (2) thicker, less permeable disposal cell covers, (3) improved compaction of disposal cell contents and covers, (4) stacked disposal of waste rather than random disposal, (5) grouting of disposed wastes, (6) decontainerized disposal of low-activity compressible wastes, and (7) use of engineered structures such as concrete-walled trenches.

The waste form (coupled with site design and operating practices) is probably the most significant factor contributing to site instability--a factor containing the paradox that much if not most of the problems with site instability and high maintenance costs is caused by the wastes containing the least activity. Most of the waste sent to LLW disposal facilities consists of very low activity material such as trash which is frequently easily degradable. In the past, some of this waste has been packaged in easily degradable packages such as cardboard boxes. Most of the waste, however, is currently packaged in longer-lasting, but still degradable, rigid containers such as wooden boxes and 55-gallon steel drums. Large void spaces can also exist within waste packages and the disposal cells after waste disposal. As the waste material degrades and compresses, a process which is accelerated by contact by water, additional voids are produced. This leads to settlement of the disposal cell contents, followed by subsidence or slumping of the disposal cell cover. This increases the percolation of water into disposal cells, accelerating the cycle. This slumping and subsidence is frequently quite sudden.

The use of the rigid containers would be expected to reduce the amount of short-term subsidence. Over the longer term, however, subsidence problems would still be observed, and factors contributing to this include: (1) the waste contained in the rigid containers is still frequently easily degradable and (2) even if the waste is not readily degradable (e.g., activated alloy metal), it is frequently packaged into containers so that large voids are left within the containers. The rigid containers initially provide some structural support to the disposal cell covers, and act to "bridge" voids within the disposal cell and waste packages. Eventually, however, this structural support is lost as the rigid containers rust or rot out, leading to disposal cell settling at rates which are difficult to predict. The basic problem is the production of voids. If a waste container were completely filled with relatively nondegradable, noncompressible materials--e.g., activiated metal with void spaces within the container filled with sand--and disposed so that voids between waste packages could be eliminated, then degradation of the waste package would not be expected to result in a subsidence problem.

In Chapter 5 of the main text, an extensive case study was performed including alternate site characteristics, waste forms and packages, disposal facility designs, and facility operational procedures. Twenty separate cases were considered in the case study. The alternatives were principally directed at improving long-term site stability (e.g., reducing void spaces within the waste and trench after disposal) and eliminating the contact of water with the waste both during and after operations. They included changes which could be implemented with little additional effort and increased cost, and those involving high effort and increased cost.

These alternatives included the following:

1. Alternatives Examined to Achieve Stability

   - Compaction of backfill (and waste) during operations
   - Use of improved waste forms and packaging
   - Stacking of waste packages
   - Walled trenches and other engineered techniques
   - Segregation of stable and unstable wastes
   - Decontainerized disposal

2. Alternatives Examined to Reduce Water Contact with Waste

   - Thicker, compacted caps
   - Moisture barriers
   - Improved waste forms and packaging
   - Walled trenches and other engineering techniques
   - Segregation of stable and unstable wastes
   - Use of a permeable backfill

The case study with its many nuances is too extensive to be reproduced here. From the analysis, however, NRC believes that the siting, design, operation, and closure of the disposal facility should be clearly directed toward achieving the maximum practical site stability. Disposal facility stability and the corresponding potential for ground-water migration directly affect the level of long-term care and maintenance by the site owner. Past experience with LLW disposal clearly indicates that one of the most important objectives of LLW disposal should be that the disposal facility is stabilized so that little or no maintenance is required by the site owner. NRC staff believes that the alternative of not considering this as a performance objective is clearly not acceptable.

Although the stability performance objective is needed, care is required in implementation to arrive at an equitable distribution of costs. Much of the waste sent to LLW disposal facilities consists of very low-activity material such as trash which is frequently easily degradable and compressible. This complicates the analysis, since most of the waste streams that contribute the most to site instability are the same waste streams that contain the least activity. Much of this low-activity waste is only suspected of being contaminated and/or is generated by small waste generators such as hospitals and research laboratories. These factors increase the difficulty of arriving at a cost-effective solution to the problem of disposal facility instability. That is, it is difficult to justify requiring large additional expenditures to dispose of otherwise low hazard material.

One alternative would be to incinerate and solidify all combustible waste streams. In general, although NRC staff believes that waste incineration may be a cost-effective solution for some waste generators, it would cause economic hardships if required generally, particularly to small waste generators such as hospitals and research laboratories. Costs would run on the order of $\$927/m^3$ ($\$26.25/ft^3$). In addition, it is not a solution that could be generally instituted on a reasonable time basis. Other alternatives such as extensive engineered disposal techniques (e.g., grouted or concrete-walled trenches, decontainerized disposal) also appeared to have a number of drawbacks for general application. These drawbacks included significant additional disposal costs and significantly increased occupational exposures at the disposal facility. For example, additional disposal costs would run at about $60.50/m^3 ($1.70/ft^3) for grouted disposal, $211/m^3 ($6/ft^3) for disposal into a grouted concrete-walled trench, or $49/m^3 ($1.40/ft^3) for decontainerized disposal.

The most reasonable alternatives considered--those which could be implemented with reasonable costs and within a reasonable time frame--involved stabilization of higher activity waste streams coupled with segregated disposal of lower activity unstable waste streams. Segregation is estimated to cost an approximate additional $6/m^3 ($0.17/ft^3). Stabilization of the higher activity streams could be accomplished by either stabilizing the waste form (e.g., through solidification), stabilizing the waste package (e.g., through use of high-integrity containers), or by disposal facility design (e.g., by placing the waste into a structure which supports barriers to moisture). Once the disposal cells are stabilized, then improved barriers to moisture may be emplaced, further reducing exposures to levels as low as reasonably achievable.

This means that there still may be some long-term maintenance required for the segragated low-activity waste disposal cells. However, since the activity contained in these disposal cells would be relatively low, the impacts from increased percolation into these disposal cells would also be relatively low. In addition, long-term maintenance can be reduced through such improvements in facility design and operating practices as:

- improved backfill;
- improved disposal cell covers;
- increased attention paid to minimizing voids in disposal cells; and
- improved compaction of disposal cell covers.

Such improvements, which are estimated to cost an approximate additional $22/m^3 ($0.62/ft^3) in operational costs above the base case, are already being implemented to a certain extent at existing operating disposal facilities. Thus, implementation of such practices would involve few additional costs to waste generators.

Readily achievable improvements in waste form which would reduce long-term maintenance include the following:

- additional compaction of compressible wastes;
- increased attention paid to minimizing voids in waste containers; and
- use of longer-lasting waste containers.

The first two of the above options are already being carried out by a number of waste generators.

In regard to improved containers, polyethylene drums are available, for example, which have been certified by DOT for use in transporting nonradioactive hazardous wastes such as oxidizers or corrosive solids. These are apparently available at approximately the same (or possibly reduced) price as standard steel 55-gallon drums. Compared to steel 55-gallon drums, which is the most common type of waste container used in the nuclear industry, a polyethylene or other type of plastic drum would be expected to degrade very much slower after disposal, provided that the drum is designed to be compatible with the waste form and the disposal environment. The radionuclide containment capability would therefore be expected to be greater than a typical steel 55-gallon drum. More importantly, reduced container degradation would result in reduced compression of disposal cell contents, thus reducing subsidence and infiltration of water.

If the above options were generally carried out, then it is possible that the level of maintenance required for the low-activity disposal cells can be reduced to very low levels.

Given this overall objective--the need for disposal facility stability--numerical limits for migration were derived.

The EPA has a program underway leading to development of a standard for long-term releases of radioactivity to the environment from LLW disposal facilities. In the absence of that standard, NRC considered existing NRC and EPA standards and narrowed the range of alternatives to be analyzed in this EIS to a range of 1-25 mrem/year. One mrem/year was selected as a lower bound since it was less than the 4 mrem/yr limit in EPA's national primary drinking water standard (40 CFR Part 141), and it would provide a low limit against which the ability of current technology to meet such a limit could be analyzed. Twenty-five mrem/year was selected as an upper bound since it was already in use as an existing EPA standard (40 CFR Part 190) applied to routine operating releases from nuclear fuel cycle facilities.

Based on the analyses, NRC concluded that a limit in the range of existing EPA drinking water regulations (4 mrem/yr) can be achieved at the nearest public drinking water supply given some modest increased costs and changes. NRC also concluded that meeting the EPA drinking water standards at the nearest public drinking water supply results in annual potential exposures of less than 25 mrem whole body, 75 mrem thyroid, and 25 millirem to any other organ to an individual who might consume water from a well located at the site boundary.

An annual exposure limit of 25 mrem whole body, 75 millirem thyroid, and 25 mrem to any other organ to the maximally exposed individual at the site boundary coupled with an annual population limit of 4 mrem at the nearest public drinking water supply was, therefore, selected as the preferred performance objective. Because of the need to consider other potential environmental release pathways, albeit small, the performance objective includes potential releases from surface water, air, plants, and animals. Broad public acceptance of the application of the EPA drinking water standard and the existing fuel cycle standard at the site boundary was also expressed in the public comments and workshops on the preliminary draft Part 61 rule.

Moderate changes in waste form and packaging and disposal facility design and operating practices are needed to meet the selected performance objectives. These principally include methods by which the stability of the disposal facility can be enhanced:

1. Stabilization of higher activity waste streams;

2. Segregated disposal of low activity unstable waste streams from stable wastes;

3. Improving site stability through operation techniques such as improved backfilling and compaction; and

4. Reducing contact of waste with water.

Many of the the higher costs which would be associated with the stabilization of higher activity wastes represent activities that many waste generators are already carrying out to meet existing disposal facility license conditions.

5.1.3 Assuring Safety During Operations

The function of a near-surface radioactive waste disposal facility is to contain disposed radionuclides over the long term, and potential long-term impacts are of major concern in licensing an LLW disposal facility and in determining disposal requirements for specific types and forms of waste. However, protection of public health and safety during the operational phase of the disposal facility is also of concern when licensing the facility and regulating its operation. As part of the analysis performed in Chapter 6 of this EIS, NRC determined that existing standards in the NRC regulation 10 CFR 20 were an adequate performance objective for operational safety. The Part 20 regulation already provides standards for control of and limitation for release of radioactive materials to the environment from operations at NRC-licensed facilities, as well as limitations on the allowable radiation doses to radiation workers and the public.

5.2 Technical Requirements

Based upon the analyses for the performance objectives, a number of technical requirements were developed to help ensure that the performance objectives would be met. These technical requirements are set out in Subpart D of the Part 61 rule. (See Attachment A to this summary.) The technical requirements generally either fell directly from the analysis to determine the performance objectives or were developed based upon past experience and existing good practices. A given technical requirement frequently helps to ensure that more than one performance objective will be met.

Most of the technical requirements can be related to three key principles that are of most significance in assuring the performance objectives are met. These three principles are:

1. Long-term stability of the disposal facility and disposed waste. Trench cap collapse, subsidence, increased water infiltration,

and the need to actively care for the facility over the long term are all reduced if stability is ensured.

2. The presence of liquids in waste and the contact of water with waste both during operations and after the site is closed. Water is the primary vehicle for waste transport and its presence in and contact with waste can contribute to accelerated waste decomposition and increased potential for making the waste available for transport offsite.

3. Institutional and other engineering and natural controls that can be readily applied to reduce the likelihood and impacts of inadvertent intrusion.

The following chart summarizes the relative importance of each in helping to assure achievement of each of the performance objectives.

	Performance Objectives			
	Migration	Maintenance	Intruder	Operations
Long-term stability of waste and facility	Reduces water infiltration and thus the potential for migration.	Reduces uncertainty and need for long-term maintenance. Reduces long-term care costs.	Reduces likelihood for inadvertent intrusion. Reduces impacts to inadvertent intruder.	Reduces potential occupational hazards. Reduces off-site releases in the event of an accident.
Contact of water with waste	Reduces potential for migration and offsite transport of waste	Reduces need for active maintenance during and after operations.	Reduces waste degradation and thus impacts to intruder.	Reduces potential hazards. Reduces potential for offsite releases.
Institutional and other intruder controls	Custodial care during institutional control reduces potential for water infiltration.	Assures proper maintenance.	Reduces likelihood for inadvertent intrusion. Reduces impacts to inadvertent intruder.	Reduces potential occupational hazards.

As discussed below, safety during disposal facility operations is also an important consideration.

Stability

In translating these principles into technical requirements, NRC found that in general many were already being addressed in one way or another at one or more of the existing operating sites. For example, methods to improve site stability which are either already being carried out or may be readily implemented include improved, more stable waste forms and packaging for higher activity wastes, reducing void spaces between packaging placed in trenches, compaction of backfill material and trench covers, and use of institutional controls to continue to maintain and control site access after active operations cease.

The preferred alternatives selected will result in the least disruption of existing practices and will leave maximum flexibility in how stability can be achieved. The preferred alternative is to require that higher activity wastes must be placed into a stable form and segregated in disposal. Waste segregation is estimated to cost an approximate $6/m³ ($0.17/ft³) in additional disposal costs. Stability of the waste form can be achieved by several means:

1. The waste form itself (results in no increase in costs over those today);

2. Processing the waste to a stable form through techniques such as improved packaging, use of high integrity containers, or waste solidification (the costs for this can range from negligible additional packaging costs to an approximate additional $450/m³ for high integrity containers up to about an additional $2000/m³ in solidification costs. The costs are believed to be conservatively high. In any case, the industry is generally already moving toward this alternative and it is, therefore, not a significant change from existing practices);

3. Use of engineering design at the disposal facility. Many engineering design alternatives are possible including caissons filled with concrete and concrete-walled trenches. (The cost for a concrete-walled trench including use of concrete grout as a backfill material was estimated to cost an approximate additional $211/m³ ($6/ft³) in disposal costs.)

NRC also evaluated a number of facility design and operational improvements that are in many cases currently being applied at the existing operating sites to improve long-term site stability. These include waste placement, backfill, and compaction of backfill and trench covers. The use of specific design and operational techniques would be evaluated for a specific facility on a case-by-case basis as part of licensing that facility.

Contact with Water

A number of specific requirements relating to site characteristics, disposal facility designs and operating practices, waste forms and packages, and institutional controls are established which are directed at reducing the contact of water with waste, both during operations and over the long term after closure (See Sections 61.50, 61.51, 61.52, 61.56, and 61.59). These included requirements that the site be free of areas of flooding or frequent ponding and providing sufficient depth to the water table that ground-water intrusion into the waste will not occur. They also included design features such as trench covers being designed to prevent water infiltration, to direct rainwater away from trenches and to prevent waste from sitting in rainwater in open trenches. Waste form requirements address the disposal of liquid waste. The minimum requirements provide that waste containing liquids must be packaged in sufficient absorbent material to absorb twice the volume of liquid. Higher activity wastes containing liquids must be converted into a stable form that contains not more than 1% free-standing liquid by volume.

Institutional Controls

Since the use of institutional controls to control site access and to monitor and care for the site over the long term is current practice, NRC included the costs for 100 years of active institutional control in the costs for the base case (reference) disposal facility. As such, this requirement reflects current practice and does not represent an increased cost over that today. The potential costs for maintenance of the site during this period can, however, vary depending upon the degree of site stability. As discussed above, the requirements in Part 61 directed at site stability should reduce the need and costs to actively maintain a site during this period.

Institutional controls (physical activities of man such as site surveillance or inspection) shall only be relied upon for 100 years following site closure to keep people from inadvertently intruding into the site and to carry out an environmental monitoring program and minor custodial care (see Section 61.59).

Safety During Operations

An applicant's or licensee's operational procedures and programs for compliance with the operational safety performance objective would be evaluated on a case-by-case basis. NRC staff believes that this approach would be preferable to setting out a number of prescriptive requirements for safe facility operation. Measures which could be used to minimize potential operational releases and exposures will be influenced by site-specific conditions at the particular disposal facility considered. Detailed prescriptive requirements would also inhibit incorporation of potential improvements in site safety. Some of the procedures and programs which would be analyzed as part of a specific application would include the following:

- The applicant's radiation safety program for control and monitoring radioactive effluents and occupational radiation exposure to demonstrate compliance with the Part 20 requirements and to control contamination of disposal facility personnel, vehicles, equipment, buildings, and grounds. Both routine operations and accidents would be addressed, and the program description would include procedures, instrumentation, facilities, and equipment.

2. Consideration of potential hazard to an individual or a population from potential consumption or use of contaminated ground water.

A classification system based on these two considerations--intrusion and migration--presents some difficulties in calculating acceptable concentration limits for waste. The calculation of concentration limits for exposures to an inadvertent intruder are relatively straightforward since the potential exposures are directly related to the concentrations of the radionuclides available for uptake. In addition, potential intruder exposures are relatively less site-specific.

It is considerably less straightforward to set out categories of waste based upon consideration of ground-water migration. Potential ground-water migration impacts could occur from consuming water from a well located onsite, consuming water from a well located at the site boundary, or to populations consuming water down-gradient of the site. Potential migrational impacts are much more a function of site-specific environmental and geohydrological conditions than concentration-limited intruder impacts. Potential migrational impacts are furthermore a function of the total inventory of radionuclides at a disposal site.

Combining these two considerations, the approach that has been taken is to first determine waste classification requirements (based upon concentration limits) considering protection of a potential inadvertent intruder. Second, based on the analyses in Chapter 5, four radionuclides were identified that are of significance from the standpoint of migration. These are H-3, C-14, Tc-99, and I-129. These nuclides have been addressed on a site-specific inventory basis. That is, the total quantity of these four radionuclides acceptable for disposal at any particular site will be determined as part of the licensing process based on the specific hydrogeological conditions, facility designs, and operating procedures at the site. The waste classification procedure proposed by NRC is summarized as Table 1 in the attached Part 61 rule (see Section 61.55 of the rule).

6.1 Classes of Waste

Three classes of waste are determined by the Part 61 requirements:

1. Wastes for which there are no stability requirements but which must be disposed of in a segregated manner from other wastes. These wastes, termed Class A segregated wastes, are defined in terms of maximum allowable concentrations of certain isotopes and certain minimum requirements on waste form that are necessary for safe handling.

2. Wastes which need to be placed in a stable form and disposed in a segregated manner from unstable waste forms. These wastes, termed Class B stable wastes are also defined in terms of allowable concentrations of isotopes and requirements for a stable waste form as well as minimum handling requirements.

3. Wastes which need to be placed into a stable form, disposed in a segregated manner from nonstable waste forms, and disposed of so that a barrier is provided against potential inadvertent intrusion

- The applicant's quality assurance program for siting, design, construction, and operation of the disposal facility, and the receipt, handling, and emplacement of waste. Audits and managerial controls would be included as part of this program.

- The applicant's procedures and plans for construction and operation of the disposal facility. These would include methods of construction; waste emplacement; procedures for and areas of waste segregation; types of intruder barriers; onsite traffic and drainage systems; methods and areas of waste storage; and methods to control surface water and ground-water access to the wastes.

- The applicant's environmental monitoring program to provide data to evaluate potential health and environmental impacts, as well as plans for taking corrective measures if migration of radionuclides is indicated.

- The applicant's administration procedures to control activities.

- The applicant's physical security measures.

- If the application includes the proposed receipt, possession, and disposal of special nuclear material, the procedures and provisions for criticality control.

Despite this, however, NRC analyzed some potential impacts associated with facility operation and concluded that many of the same requirements that would reduce long-term environmental impacts and impacts to a potential intruder would also help reduce operational impacts. For example, segregated disposal of low activity compressible wastes from stabilized high activity waste--which reduces exposures to an inadvertent intruder, reduces ground-water migration and reduces long-term maintenance of the disposal facility--would also tend to reduce the impacts of a potential accidental fire in a disposal cell. Stabilizing high activity waste streams reduces the impacts of a waste container potentially dropped accidentally from a height and releasing part of the container's contents.

Finally, NRC identified some specific general waste form and packaging requirements that have been developed and applied in the past at disposal facilities. These requirements provide protection of the health and safety of site workers, facilitate handling of waste, and minimize the potential for releases to offsite areas. These requirements have been condensed from consideration of current practices at existing disposal facilities and are summarized in Section 61.56 of the proposed rule as minimum waste form and packaging criteria.

6. WASTE CLASSIFICATION

Based upon the analyses in Chapters 4 and 5, there are two fundamental mechanisms to classify wastes for long-term hazard:

1. Consideration of potential hazard to an inadvertent intruder due to direct contact with the disposed waste; and

after institutional controls have lapsed. These wastes are termed Class C intruder wastes and are also defined in terms of allowable concentrations of isotopes and requirements for disposal by deeper burial or some other barrier.

Upper concentration limits are also defined for Class C waste. Wastes containing concentrations higher than the upper limits would be generally unacceptable for near-surface disposal. The disposal of such wastes should be subject to case-by-case determinations depending upon the specific waste forms and disposal techniques. In addition, four isotopes--H-3, C-14, I-129 and Tc-99--require site-specific inventory considerations to assure the performance objective for long-term environmental protection is not exceeded.

6.2 Maximum Average and Allowable Concentration Limits

The radionuclides concentrations calculated by NRC represent maximum average concentrations in disposed waste. If they were applied as allowable concentration limits, the actual average radionuclide concentration in the disposed waste in any disposal facility would be less and, in most cases, significantly less than the calculated maximum average concentrations. This is due to the mixing or dilution of all the various waste stream packages containing varying concentrations of radionuclides during disposal.

To help in maintaining exposures to levels as low as reasonably achievable, the NRC staff believes that calculated maximum average concentrations should be used. This reduces the potential long-term hazard from long-lived radionuclides. NRC staff also believes, however, that there should be flexibility and that exceptions should be considered when there is good reason to do so.

A specific example in this letter is the isotope Cs-137. This isotope, which is a beta-gamma emitter having a half-life of about 30 years, is present in significant quantities in some wastes. For example, from 25 to 75 percent of the activity in spent LWR resins can be due to Cs-137. In the analyses performed in Chapters 4, 5, and 6, concentrations of Cs-137 were used which were based upon geometric means of a number of data points. However, there was a considerable range in the concentrations. It is therefore possible that the analysis in Chapter 4 could underestimate the volume (and costs) of LWR wastes which would have to be processed and disposed by more expensive means. If the Cs-137 concentrations were a factor of 10 higher, the overall intruder hazard at 100 years would be increased some, but the volume-weighted hazard would still be less than 500 millirem/yr. Use of the higher concentrations would not effect the long-term potential hazard.

The Cs-137 concentrations were, therefore, raised by a factor of 10 for Class B and Class C waste, and for the maximum concentration generally acceptable for near-surface disposal. A somewhat higher factor--i.e., 20--was applied to the interface concentration between Class A and B wastes to account for the preponderance of trash in Class A waste which contain very low concentrations of cesium or none at all. As noted, increasing the cesium concentration does increase the short-term potential hazard somewhat but not above the 500 mrem/yr performance objective. The long-term potential hazard does not change.

6.3 Transuranic Isotopes

Based upon work performed for this environmental impact statement as well as work performed by others, NRC decided not to raise the existing working limit of 10 nCi/gm for transuranic isotopes. This decision is based on several factors. For most of the alpha-emitting transuranic radionuclides, the maximum average concentrations calculated were in the range of 10 nanocuries per gram. As noted above, these concentrations are conservative in that they do not consider credit for dilution by other wastes.

In the spirit of the ALARA concept, the lower value of 10 nCi/gm has been demonstrated as an achievable concentration to control the disposal of transuranic nuclides by near-surface disposal. This value has been imposed by the Department of Energy for some eleven years and by most of the commercial disposal site operators for nearly that long. The last commercial site imposed the 10 nCi/gm restriction in 1979. In addition, it is believed that most of the potential for economic gain that would result from a higher limit (say in the range of 100 nCi/gm) could be negated by current limitations in routine measurement techniques. There is also a tendency toward a more conservative assessment of the hazard of certain transuranic nuclides (e.g., as in ICRP-30) and it does not seem prudent at this time to use higher values. In adopting the existing limit of 10 nCi/gm, NRC staff recognizes that the principal concern regarding potential future health hazards of TRU disposal is due to long-lived alpha activity. One exception to this rule would be Pu-241, which is a beta emitter which decays with a 13.2 year half-life to Am-241, which is an alpha emitter having a half-life of 458 years. The ratio of the specific activity of Pu-241 to Am-241 is about 35. Thus, to maintain an equivalent limit for alpha emitters of 10 nCi/gm, a limit of 350 nCi/gm will be allowed for Pu-241.

6.4 Isotopes Not Included in Table 1

NRC calculated and set out in Table 1 of the proposed Part 61 rule, limiting concentrations for 11 isotopes having half-lives over 5 years; natural, depleted, and enriched uranium; plus transuranic radionuclides. These are believed to generally cover many, if not most, of the longer-lived radionuclides currently delivered to a disposal facility. Of the hundreds of radioactive isotopes that have been identified, most have half-lives not exceeding 5 years. A limit for isotopes with a half-life of less than 5 years is also included in Table 1. For Classes A, B, and C waste, the concentration limit for Co-60 was used. As shown in the table, there is no upper bound allowable concentration for such isotopes since the calculated limits exceed the natural specific activity of the isotopes. Using the Co-60 concentration for Classes A, B, and C is believed to be conservative since Co-60 has a half-life greater than 5 years and emits two energetic gamma rays.

NRC also recognizes that there are several other isotopes (e.g., thorium and radium) for which concentration limits should be developed. Others may also be identified. NRC plans to analyze development of limits for such radionuclides subsequently. In the meantime, some working concentration limits should be considered for isotopes not presently analyzed. For these, NRC believes a reasonable, yet conservative, approach would be the following:

- Use of values for Sr-90 for beta-emitting isotopes with little or no gamma radiation;
- Use of values for Cs-137 for beta-emitting isotopes having significant gamma radiation; and
- Use of values for enriched uranium (U-235) for alpha-emitting isotopes other than radium.

For radium, no limits are established as of yet. In addition, NRC calculated limits for U-235 and U-238 and applied them as the limits for enriched uranium (U-235) and natural and depleted uranium (U-238). The use of U-238 for depleted uranium appears acceptable, but a calculated limit may be different for natural uranium which would include consideration of daughter isotopes. As noted above, NRC plans to further develop in the near future limits for nuclides not presently analyzed, including limits for natural uranium, U-233, and other isotopes.

6.5 Mixtures of Radioisotopes

Table 1 lists concentrations for single isotopes. However, LLW packages delivered to disposal facilities seldom contain just one radioisotope; generally, the waste packages contain a mixture of radioisotopes. To account for this mixture, NRC staff proposes to apply a sum-of-the-fractions rule similar to that described in Table II of the existing 10 CFR Part 20. That is, the sum of ratios of an isotope concentration in waste to the concentrations in the table shall not exceed unity for any waste class. That is,

$$\frac{C_a}{C'_a} + \frac{C_b}{C'_b} + \frac{C_c}{C'_c} \leq 1, \text{ where}$$

C_a, C_b, C_c = concentrations in waste of isotopes a, b, and c;

C'_a, C'_b, C'_c = limiting concentrations in a given waste class for isotopes a, b, and c.

In addition, concentrations may be averaged over the volume of any package. For example, for a 55-gallon drum, the concentration limits may be multiplied by a factor of 200,000 (the approximate volume of a 55-gallon drum in Cm^3) to determine the allowable total activity that could be placed in a 55-gallon drum.

6.6 Implementation of Waste Classification

To implement a waste classification requirement, it will be necessary for waste generators to identify and quantify specific radionuclides in the final waste form as shipped for disposal.

In some cases, the identity and concentrations of radionuclides in each waste package will be extremely difficult to determine--particularly for radionuclides which require complex, expensive, and time-consuming analytical procedures.

Thus, in some cases, it is not practical to determine the concentrations of all relevant radionuclides by direct measurement. One solution could be to routinely measure only those radionuclides that can be reasonably and accurately measured without terribly expensive and sophisticated techniques. Concentrations of other radionuclides would be scaled to the measured radionuclides based upon existing or generator-specific data.

For purposes of review and comment, NRC has prepared a specific example on the use of scaling factors and action levels for LWR waste streams which is set out in Chapter 7 of the main text. The example reflects the type of guidance which could be set out in a regulatory guide on classification of waste. Two radionuclides which are present in relatively high concentrations in LWR waste streams and can be readily measured by gamma spectroscopy are Co-60 and Cs-137. In the procedure, these two isotopes would be routinely measured and the concentrations of other radionuclides would be estimated based upon scaling factors developed from either data specific to the facility or from a set of reference scaling factors developed from existing data.

7. ADMINISTRATIVE, PROCEDURAL, AND FINANCIAL ASSURANCE REQUIREMENTS

This section summarizes the principal administrative, procedural, and financial requirements set out in the proposed Part 61 rule. The principal administrative and procedural requirements on disposal facility operators are presented first (in Section 7.1), and are discussed in the context of the expected life cycle of a typical LLW disposal facility. The financial requirements are then presented in Section 7.2. Finally, the proposed new waste manifest tracking system, which effects waste generators and waste transporters as well as disposal facility operators, is discussed in Section 7.3.

7.1 Procedural and Administrative Requirements on Disposal Facility Operators

The life cycle of a disposal facility can be divided into five phases: (1) preoperational phase, (2) operational phase, (3) closure phase, (4) observation and maintenance phase, and (5) institutional control phase. These five phases are summarized in Figure S.2 and discussed in more detail below.

Preoperational Phase

The preoperational phase consists of disposal site selection, characterization, and licensing. Disposal site selection and characterization is a period of data gathering and planning. The applicant selects a region of interest and searches for a number of possible disposal sites (a slate of candidate disposal sites) using reconnaissance-level information. The applicant then narrows the possible sites down to one. After a proposed disposal site has been selected, the applicant begins a detailed investigation (geology, depth to ground-water table, amount of rainfall, etc.) of the proposed disposal site. The applicant also initiates the preoperational monitoring program.

The applicant prepares an application for the land disposal facility following Subpart B of Part 61. The applicant also prepares an environmental report. Of particular importance to this application are the methods by which the applicant

Figure S.2 Life Cycle and Financial Assurances for a Disposal Facility Following the Proposed 10 CFR Part 61

Time in Years	Activity	Form of Financial Assurance
1-2 yrs	Site Selection and Characterization	Licensee responsible for costs incurred
1-2 yrs	Licensing Activities	Licensee responsible for costs incurred including licensee fee
		Site closure plan including cost estimates for closure is submitted as part of licensee application
		Lease arrangement with long-term care arrangements for financial responsibility between licensee and state submitted for review to NRC for adequacy
		Licensee obtains adequate short-term sureties to provide for closure
20-40 yrs	License Issued; Site is in Active Operation; Waste Received	Short-term sureties in place for closure: NRC periodically reviews and requires updating to account for changes in inflation, site conditions, etc.
		NRC periodically reviews revisions to lease arrangements to ensure that arrangements for financial responsibilities for long-term care are adequate
1-2 yrs	Site Closure and Stabilization	Costs covered from short-term sureties, if necessary; otherwise, licensee performs activities
		Lease arrangement between site owner and operator for long-term care is still in effect
5-15 yrs	Observation and Maintenance	Licensee still responsible for all further costs during this period, with short-term assurances still in place
100 yrs	License Transferred to Site Owner; "Active Institutional Control Period"	Terms and conditions of lease are met, and either state or licensee provides funds to pay for all required and necessary activities of this period

will comply with the Part 61 performance objectives and technical requirements, the preliminary site closure plan, arrangements concerning land ownership and associated responsibilities, and financial assurance.

Licensing activities begin when the applicant files the application. Prior to docketing, the application is reviewed for completeness and acceptability in accordance with the new ¶2.101(b)(2). A notice of receipt of the tendered application is published in the Federal Register. The Commission notifies state, local, and tribal officials and begins to coordinate with these officials. Once docketed, the application is again noticed in the Federal Register and the application and accompanying environmental report widely distributed. An opportunity for interested parties to request a hearing is provided pursuant to 10 CFR 2.105. Application fees are paid in accordance with 10 CFR Part 170.

The regulatory review period follows. The applicant continues any disposal site studies and the preoperational observation and monitoring. The applicant also responds to informational requests from NRC. Section 61.3 requires that construction not begin until a decision is made to issue the license. The application and environmental report are updated if necessary.

Based upon the application, environmental report, and any additional information, the Commission prepares a draft environmental impact statement (DEIS) and publishes it for public comment. Based upon public comments and any additional information, the staff prepares and publishes a final environmental impact statement (FEIS). If hearings are requested, an Atomic Safety and Licensing Board (ASLB) is appointed. Hearings, if any, would be held in accordance with existing rules in 10 CFR Part 2. An Atomic Safety and Licensing Appeal Board and/or the Commission may review the findings of the ASLB, or the ASLB findings may be appealed to these next levels and to the courts. Upon resolution of the hearings, reviews, and appeals, the Director* takes final action to issue or deny the application in accordance with the criteria in Section 61.23, plus any conditions rendered by the Licensing or Appeals Boards or the Commission. A notice is published in the Federal Register in accordance with Section 2.106. If the ownership of the land has not been transferred to the state or federal government, transfer would now take place. If the license is issued, it is subject to the general license condition in Section 61.24 and to specific conditions as required.

States and Indian tribes may participate in the Commission's license review process. Subpart F of the proposed Part 61 rule addresses such participation, which is in addition to participation as already provided in Parts 2 and 51. Examples of the forms that state and tribal participation may take include:

1. Development of technical data, including but not limited to, socio-economic, hydrological, geological, environmental, or land use data for incorporation into the Commission's environmental impact statement on the application or other analyses.

*The "Director" means the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission.

2. Development of public participation mechanisms to be included in the licensing process.

3. Provisions of a technical data base to provide verification to the Commission for materials presented in the license application.

4. Exchange of state and Commission staff for cooperative review.

Operational Phase

After issuance of a license by the Commission, the land disposal facility is constructed and waste receipt and disposal operations start. At intervals specified in the license (the normal term for materials licenses is currently 5 years), the licensee would be required to submit a license renewal application (Section 61.27). At this time, the disposal site closure plan and funding requirements would be updated and financial arrangements for assurance of adequate funding reviewed. A public hearing would be offered. The licensee may also apply for amendments to the license at any time during the operational phase (Section 61.26).

Disposal Site Closure Phase

As the disposal site becomes filled, the time for disposal site closure approaches. Prior to closure, the licensee would submit a final closure plan for review and approval (Section 61.28). A public hearing would be offered. Upon approval, the licensee implements the plan. This would consist of decontamination and dismantlement, as appropriate, of buildings or other site facilities. Final disposal site contouring and preparation is performed. The licensee should work toward closure during the entire operational phase so that disposal site closure would not involve a major task.

Postclosure Observation and Maintenance

Implementation of the closure plan would be followed by a period of postclosure observation and maintenance on the part of the licensee, in which the licensee's monitoring and maintenance programs would continue.

This period is expected to last about 5 years and will help assure that the disposal site is in a stable condition so that only minor care, surveillance, and monitoring by the custodial agency are required. When the disposal site has reached a stable condition, the licensee may prepare and submit an application for transfer of the license. A public hearing would be offered. Among other things, the licensee must provide reasonable assurance that the site meets all performance objectives under Subpart C, and the Commission must find that the state or federal agency responsible for postclosure care of the site is prepared to assume these responsibilities. As a condition for assuming these responsibilities, a state may require the licensee to comply with requirements of its own, as long as the state's requirements are not inconsistent with the requirements of the Commission. Upon a satisfactory finding, the license will be transferred to the federal or state custodial agency to cover their activities during the active institutional control period (Section 61.30).

Institutional Control Period

During the institutional control period, which for purposes of Part 61 the Commission assumes to be not more than 100 years, the custodial agency carries out a program of monitoring and physical surveillance to assure continued satisfactory site performance, as well as other minor custodial activities. As a part of the license termination requirements, the licensee is required to place records of the disposal facility with local, state, and federal agencies. These records along with restrictions on the property deed and trench markers should help minimize disturbance of the disposal site. These latter mechanisms are those that would continue after the active institutional control period. At the end of the necessary institutional control period, the custodial agency license may be terminated (Section 61.31).

7.2 Financial Assurance Requirements

Financial assurance requirements for low-level waste disposal facilities are needed to help ensure the long-term protection of public health and safety and the environment. A review by the staff of the operating experiences at both hazardous waste and LLW disposal sites reveals that operators of both types of sites did not adequately plan for closure and long-term care activities. With respect to LLW sites, the state and federal governments recognized the need to care for the sites over the long term. The sites had to be located on land owned by the federal or state government and funds were collected for long-term care activities. In most cases, however, the funds collected for long-term care activities (e.g., the Maxey Flats, Kentucky site) were not adequate and there was essentially no financial planning for contingencies that might occur (e.g., the need to pump trenches and treat trench leachate). In addition, until recently little planning or financial assurance was provided for funding final closure and stabilization of the existing sites. This has led to a situation where financial responsibility for the continued assurance of protection of the public health and safety at several of the existing closed sites already has or could become a responsibility of the state or federal government. Closure, postclosure, and active institutional control costs are generally incurred after the site operator is no longer receiving revenues from waste generators. Thus, proper planning during the operating phase when revenues can be accrued is essential.

Based on these considerations, there is a strong need for regulatory requirements to ensure that: (1) the licensee has sufficient financial resources to construct and operate the facility and to provide for final closure and postclosure care of the site and (2) the licensee provides financial assurance for the active institutional control period after the site is closed and stabilized. The staff believes these closure and active institutional care costs should be identified early and should be provided for as part of the necessary costs of operating a site. Financial assurance mechanisms to provide for these costs should be established during the active operating period of the site, when revenues are still being received by the licensee and he has access to financial resources. The need for stringent financial requirements to ensure that the licensee is financially responsible has been voiced by a number of sources, including the U.S. General Accounting Office and the National Conference of Radiation Control Program Directors. Financial assurance requirements are set out in Subpart E of the proposed Part 61 rule.

7.2.1 Requirements for Short-Term Financial Assurances for Operations, Closure, and Postclosure Observation and Maintenance

Given the past history at some of the existing disposal sites, one of the requirements in the Part 61 rule is assurance of adequate financial qualification on the part of the applicant to construct and operate the disposal facility and to provide adequate financial provisions for disposal site closure and postoperational activities.

Short-term financial assurance mechanisms refer to arrangements intended to ensure that the licensee is financially responsible for undertaking required closure, stabilization, and postclosure activities at a low-level waste site, and would be particularly based on a specific site closure and stabilization plan. The amount of financial assurance required would be based on cost estimates submitted by the licensee in an approved plan for disposal site closure and stabilization. In the proposed rule, the applicant must submit a cost estimate for disposal site closure that includes consideration of inflation, increases in the amount of disturbed land, and the closure and stabilization activities that have already occurred at the disposal site. As used in the Part 61 rule, the concept of financial assurances does not include any requirements for third party liability coverage for damages to people or property resulting from operation of the facilities.

The proposed rule requires applicants to provide proof of financial qualifications prior to the commencement of construction of the disposal facility. Proof of the financial qualifications of applicants is not currently required by Parts 30 and 40. Requiring such financial qualification in the Part 61 rule will help assure that resources are not expended on projects without adequate backing and should minimize the potential for early default or the abandonment of the site by the operator.

The NRC has received strong public interest concerning the issue of financial responsibility for closure of a disposal site. Numerous written comments were made on this portion of the preliminary draft regulation, and the issue was also raised at all four workshops held to review this regulation. Many commenters felt that the licensee should be held responsible for the full costs of closure of a disposal site, and that the license should not be terminated and the land returned to custodial government authority until the licensee has completed satisfactory closure.

There are a variety of short-term financial assurance mechanisms that could be used by a low-level waste disposal facility operator to assure that sufficient funds are available for closure and postclosure care. Short-term financial assurance mechanisms considered by the staff included the following:

1. Surety bonds, obtained from a surety company;

2. Escrow arrangements between a bank, the government, and the licensee;

3. Trust funds, arranged between the government, a financial institution, and the licensee;

4. Certificates of deposit to a state or federal agency;

5. Cash deposits to a state or federal agency;

6. Deposits of securities to a state or federal agency;

7. Secured interests in the disposal operator's assets;

8. Letters of Credit from a financial institution;

9. Self-insurance by the low-level waste disposal facility operator;

10. Financial tests of the operator or his holding company;

11. Development of a sinking fund based on receipts from surcharges on received wastes; and

12. Development of a closure assurance pool.

These types of financial assurances are standard commercial law arrangements currently being used by state and federal government agencies for the chemical waste disposal, uranium milling, low-level waste disposal, and surface coal mining industries. The staff considers these to be reasonable alternatives for consideration in this EIS.

The primary criterion considered by the staff in evaluating these alternative financial mechanisms was the degree of assurance provided by each method to ensure that funds are available to close the disposal site and to provide for all necessary activities to protect the public's health and safety. Other criteria considered by the staff included the following:

- The degree of security (or level of difficulty) in obtaining funds in case of default.

- The administrative time and expense required by the regulatory agency to implement and monitor the financial assurance mechanisms.

- The cost to the licensee of utilizing the financial assurance mechanism.

Conclusions

Based on the review of the alternative financial assurance mechanisms, the staff concluded that a number of financial assurance mechanisms exist that will provide adequate public protection to ensure that funds for closure and postclosure exist in the event that the site operator defaults or unforeseen site conditions require early closure of the site. The alternatives that the staff finds generically acceptable for a disposal facility licensee are:

- surety bonds
- trust funds
- escrow arrangements
- cash deposits

- o certificates of deposit
- o deposits of government securities
- o irrevocable letters of credit
- o combinations of the above

These alternatives were all found to be acceptable because they did not impose a significant economic burden on the license, they did not impose an administrative burden on the staff, and yet they each could be structured to ensure a high degree of confidence that funds would be available to ensure proper closure. The staff has also concluded that approving a range of satisfactory financial assurance alternatives allows the operator flexibility in selecting the mechanism that best suits his needs. These requirements are set out in Section 61.62. While the other financial assurance mechanisms discussed earlier may be acceptable in certain isolated cases, they are not acceptable to the staff on a generic basis. Plans for alternative financial assurance mechanisms not discussed here would be evaluated and approved by the staff on a case-by-case basis. The costs for short-term financial assurances have been included as part of the costs for the reference facility.

7.2.2 Requirements for Long-Term Financial Assurances for Institutional Care.

Based on a review of the operating history at existing LLW disposal sites, the staff finds that financial responsibility for long-term care (active institutional control) should be established prior to issuance of the disposal facility license. A review of the history of commercial low-level waste sites in this country indicates that there has been continuing concern by the public and by regulatory authorities over long-term financial responsibility for low-level waste disposal sites. In addition to questions over the equity issues of who pays for active institutional control over the site, the government and the public are concerned that funds be readily available for postoperational activities to ensure that the public's health and safety are continually protected.

Financial assurances for active institutional control involve the financing of any required activities at a low-level waste site after termination of the disposal facility license. These funding assurancies would cover surveillance, monitoring, and any necessary maintenance to assure that the stability and integrity of the site is maintained and that there are no disruptive human activities at the site for up to 100 years. The proposed requirements do not cover unanticipated contingencies that may occur at the site. Based on these considerations, the Commission staff concluded that requirements for financial guarantees for active institutional control should be included in the proposed Part 61 regulation.

A review of the various financial assurance mechanisms commonly used in the commercial law area (see Section 9.3.3 of the main text) revealed that few, if any, of these mechanisms are suitable for the long-term nature of a long-term financial assurance mechanism. The extended time period (100 years) means that few financial institutions are willing or able to handle that type of long-term financial assurance. There are, however, several other alternative long-term financial assurance mechanisms that can be used for active institutional control at a disposal site. Several criteria were applied in reviewing the adequacy of alternative financial assurance mechanisms for long-term care. The staff considered that the most important consideration for long-term financial assurances was the extent to which they were able to provide a guarantee that the necessary funds would be produced by the responsible parties. Another necessary consideration was the extent to which enabling authority existed to allow the Commission staff to require a specific financial assurance mechanism. Several of the financial assurance mechanisms proposed by various parties would require enabling legislation that is currently lacking at the federal level. Financial assurance mechanisms reviewed by the staff included a sinking fund funded by a surcharge recovered from disposal facility customers, an LLW disposal "superfund," and a lease or a legally binding arrangement.

Conclusions

The staff has determined that all low-level waste disposal site operators must establish evidence of financial responsibility to provide for long-term care of the site during the active institutional control period. Financial responsibility for long-term care must be demonstrated prior to the issuance of the facility license, including costs for all required and necessary activities at the site, including surveillance, monitoring, and required maintenance. States regulating existing commercial low-level waste disposal sites have traditionally required licensees to establish sinking funds based on surcharges collected from the disposal facility customers, along with leases between themselves and the operator specifying financial responsibility for long term care of the site. The staff is aware of the benefits of requiring disposal operators to require a surcharge on waste generators which is consequently deposited into a sinking fund and then invested. Such a cost recovery mechanism directly charges the benefiting parties (i.e., the waste generators) with the costs of long-term care. However, this approach cannot be required by the Commission, since the Commission lacks the legal authority to: (a) require that a long-term care fund be established and (b) require that the operator impose a surcharge on waste generators.

Since the Commission lacks the authority to explicitly require that a surcharge be imposed and a sinking fund be established, the staff considers that the next best regulatory alternative is to require that the operator be party to a binding arrangement such as a lease between himself and the site's landowner which establishes evidence of financial responsibility. (Current Commission regulations require the state or federal government to be the site landowner.) The staff is aware of the shortcomings of such an approach, but considers this the most viable regulatory alternative based on the current statutory authority of the Commission. Such regulatory requirements will help to ensure that the licensee or the site owner is responsible for performing all required long-term care activities that are necessary to protect the public health and safety and the environment. These requirements are set out in Section 61.63.

The staff has included the costs for 100 years of active institutional control into the cost of the reference facility as well as the alternatives considered in the EIS. The actual costs of long-term care, however, will vary depending upon the level of active maintenance required under varying disposal facility conditions. Long-term site stability will significantly reduce and possibly eliminate the need for any major maintenance and cost over the long term.

7.3 Manifest Tracking System

Section 20.311 of Part 20 establishes the requirements for a manifest tracking system for wastes. The system will address the need for more complete information on the classification and characteristics of the waste, for improved accountability of wastes, and for a better data base. The General Accounting Office (GAO) noted the need for improvements in these areas in its report entitled "The Problem of Disposing of Nuclear Low-Level Waste: Where Do We Go from Here?" published March 31, 1980. The GAO recommended that the Commission "determine who the generators of low-level waste are in both the Agreement and non-Agreement States and how much waste each licensee is generating" and "establish a method to track waste from the point of generation to the point of disposal." Improving the data base on waste characteristics will improve the credibility of decision-makers, enable better planning for inspections and emergencies, enhance projections of future waste generation, and help in site-specific analyses and planning. The information on waste classification and characteristics is necessary for proper handling and disposal at the land disposal facility (e.g., which waste requires intruder barriers).

Licensees who ship under existing regulations are required to prepare and forward shipping manifests that comply with DOT regulations. The proposed manifest content requirements in Section 20.311 are somewhat more comprehensive but compatible with DOT requirements. The waste generator must be specifically identified. The information requirements concerning the waste itself are somewhat more extensive and geared to information needed for disposal, not just transportation and handling. More explicit information on chemical content, waste composition, and solidification agents is required. Licensees are required to comply with and certify compliance with waste form requirements of Part 61. This latter requirement stems solely from the technical requirements for disposal and is therefore new. The land disposal facility licensee must record data on the condition of the waste itself and document and certify receipt, handling, repackaging, storage, and disposal.

The use of the manifests as provided for in Section 20.311 provides a tracking system that is inspectable. The LLW manifest tracking system is somewhat similar to the manifest tracking system recently instituted by EPA for nonradioactive hazardous wastes. Section 20.311 requires that the shipper precede and accompany shipments with copies of the manifest and investigate if notification of receipt or disposal is not received. The responsibility for tracking shipments is with the shipper who may also be the waste generator, a service company who collects, stores and delivers the waste, or an intermediate processor. A crosscheck is provided to ensure that delayed or missing shipments are investigated by requiring land disposal facility operators to periodically match advance copies of manifests to those for shipments actually received.

8. UNMITIGATED IMPACTS

As part of the EIS, NRC analyzed the potential unmitigated impacts of the proposed Part 61 regulation. In some cases, these unmitigated impacts are presented as total estimated exposures, costs, or other impacts from LLW management and disposal. In other cases, particularly when it was more convenient to do so due to lack of data, impacts are presented as incremental impacts to those which could occur without the Part 61 regulation. The unmitigated impacts are quantified to the extent practicable. Some impacts, however, can only be addressed in general terms.

Both direct and indirect impacts will occur as a result of the proposed Part 61 rule. Direct impacts are discussed first and, because this EIS is being prepared for a rulemaking action, the direct effects of the action do not fall upon the physical and natural environments, but rather upon those segments of the human environment whose conduct of affairs will be affected by the change in regulatory requirements. Among the directly affected groups are:

- Waste generators and processors;
- Waste transporters;
- Waste disposal facility operators;
- Federal agencies and the states; and
- The public.

Potential indirect impacts are addressed secondly. To estimate these impacts the performance objectives and minimal technical criteria established in this EIS are applied to four reference disposal facilities assumed to be constructed and operated on the four hypothetical regional sites.

8.1 Environmental Consequences Occurring Directly as a Result of the Proposed Part 61 Rule

Impacts on Federal Agencies

There are a number of federal agencies which have responsibilities relative to low-level waste management. These agencies are: NRC, the Environmental Protection Agency, the Department of Energy, the Department of Transportation, and the U.S. Geological Survey.

In general terms, the chief impact of the adoption of 10 CFR Part 61 on NRC would be to more clearly define to the staff the established policies, licensing procedures, and performance objectives governing LLW disposal. It would also help ensure that LLW disposal facilities are treated uniformly in terms of complying with the above regulations and procedures.

The Environmental Protection Agency (EPA) is charged with the responsibility of protection and enhancement of environmental quality and it carries out its mission through research, monitoring, regulatory, and enforcement functions. An important EPA role with regard to low-level radioactive waste management is in the establishment of generally applicable environmental standards for waste disposal. The agency does not license radioactive waste disposal facilities. The technical criteria established in the rule will not impact the ongoing EPA program for establishing overall environmental standards for waste disposal. Rather, the NRC rulemaking effort may advance EPA's efforts in this regard.

The Department of Energy (DOE) is responsible for managing disposal of low-level radioactive waste generated by government operations and for conducting research into various aspects of radioactive waste disposal. Disposal of LLW by DOE is exempted from NRC licensing authority and would remain so under the proposed Part 61 rule. One impact of the Part 61 rule on DOE would occur if DOE resumed using commercial disposal facilities for disposal of DOE LLW. Under this situation DOE would have to ensure that its waste conformed to applicable parts of the new rule.

Transportation of radioactive materials in the United States is jointly regulated by the Department of Transportation (DOT) and NRC. DOT regulates all radioactive materials in interstate commerce while NRC regulates the transportation of byproduct, source, and special nuclear material. NRC's existing regulations for transport reflect the requirements of DOT and the situation will remain the same under the proposed Part 61 rule. As a byproduct of the proposed rule, the stability requirements for higher activity wastes will help improve transportation safety, as will the minimum waste form requirements intended to improve operational safety at the disposal facility.

Impacts on the States

Promulgation by NRC of the proposed Part 61 regulation will have impacts on the states in addition to these realized by industry and federal agencies. These impacts will primarily affect those states which have entered into Agreements with NRC for regulation of certain radioactive materials--i.e., the Agreement States. The promulgation of 10 CFR Part 61 would mean that the Agreement States would have to modify their regulations to include provisions compatible with the new NRC regulation. This process of modification would involve, at a minimum, the following steps:

- Preparation of draft regulations to reflect the requirements of Part 61;
- Review and approval of proposed regulations by NRC; and
- Public review and formal incorporation into state code.

Impacts on the Public

Promulgation of the proposed Part 61 rule by NRC will impact the public most significantly. The purpose of the rule is to provide improved safeguards for protection of public health and safety and the environment, but despite these improvements, the technology of waste disposal is not risk-free. Whatever risks remain in the presence of the operative rule will be borne by the public, as will the ultimate costs of implementing the rule.

The requirements of the Part 61 regulation are expected to result in beneficial impacts to the public in three major areas. First, the implementation and enforcement of performance objectives and uniform minimum technical requirements will improve the performance of LLW disposal facilities and thereby reduce the hazards of LLW disposal to public health and safety and environmental quality. Second, the requirements of the Part 61 rule should assure that near-surface disposal remains a safe viable option for the disposal of LLW. Finally, the Part 61 rule provides public benefits in the form of more explicit provisions for participation in the licensing process for future LLW disposal facilities.

There will also be adverse impacts. The first of these impacts will be residual environmental and human health hazards resulting from LLW disposal. Despite the provisions of the Part 61 rule, the variables and processes involved in LLW disposal are sufficiently complex that unmitigated impacts cannot be avoided. Secondly, implementing the requirements of Part 61 will involve costs to the disposal facility operators, waste transporters, and waste generators. Finally, implementation and enforcement of the provisions of the Part 61 rule will require the allocation of federal and state resources during the operational and post-operational periods of an LLW disposal facility.

8.2 Environmental Consequences Occurring Indirectly as a Result of the Proposed Part 61 Rule

This section discusses the indirect impacts of the proposed Part 61 regulation. To estimate these impacts the performance objectives and minimal technical criteria established in the EIS are applied to four reference disposal facilities assumed to be constructed on the four hypothetical regional sites discussed in Chapter 3 of this summary. The site descriptions include three disposal facilities located in humid environments (northeast, southeast, and midwest sites) and one (southwest site) located in a semiarid climate. A wide range of environmental properties are represented.

8.2.1 Assumed Regional Disposal Facility Designs and Waste Source Term

This section provides a description of the disposal facilities assumed to be situated at the regional sites discussed in the preceding section, as well as the wastes which are assumed to be disposed in the facilities. The examples are intended to illustrate an upper bound range of impacts from implementation of the rule, with the expectation that actual impacts at existing or future disposal facilities would be less.

Assumed Facility Designs

All cases assume disposal into "regular" shallow land burial trenches as well as segregated disposal of waste streams containing organic chemicals as well as low activity unstable waste streams containing compressible material. Layering is used as an intruder barrier. For the three humid sites (northeast, southeast, and midwest), a moisture barrier in the form of a thick clay cap is installed and compacted using standard construction techniques. In the southwest site, however, the standard "thin" cap is assumed to be installed. Similar to the humid sites, however, the disposed waste, backfill, and cap are assumed to be compacted using improved methods (e.g., a vibratory compactor).

Due to the relatively impervious nature of the soils at the northeast site, there is a greater chance for a water accumulation problem than at the other two humid sites. For this case, therefore, and to provide one case for analysis of a more extreme engineering design, all waste packages are assumed to be stacked into disposal cells and grouted in place. At the other disposal facilities, an imported sand backfill is assumed to be used to reduce the contact time of percolating water.

All regional facilities are assumed to be operated for 20 years, followed by a two-year closure period and a five-year observation period prior to license termination and transfer of site control to the site owner.

Assumed Waste Forms

In the analysis, the higher activity waste streams are assumed to be stabilized. To provide a range of costs and impacts for the calculations, two waste spectra are considered: waste spectrum 2 and waste spectrum 1 modified by use of high-integrity containers. In waste spectrum 2, all of the LWR process waste streams are assumed to be solidified. Half are solidified in cement and half in a synthetic polymer binder. Waste streams for which most of the activity is principally contained in activated metal are stabilized using improved packages (e.g., filling void spaces within the package with a noncompressible material, use of high integrity containers, etc.). All compressible waste streams are compacted. In modified waste spectrum 1, LWR process waste streams except for solidified concentrated liquids are packaged in high-integrity containers. Concentrated liquids are assumed to be solidified. High-integrity containers are also used for packaging two waste streams containing large quantities of tritium. The other higher activity waste streams are again assumed to be stabilized through improved packaging techniques or high-integrity containers. Compressible waste streams are not compacted.

In the analysis, the volumes of waste projected to be generated in each region over a 20-year period are processed according to the waste spectra considered and delivered to the disposal facility. This results in a range in projected waste volume (in m^3) for each region as follows:

Waste Spectrum	Northeast	Southeast	Midwest	Southwest
Modified spectrum 1	9.92E+5	1.07E+6	7.56E+5	7.26E+5
Spectrum 2	6.85E+5	7.51E+5	5.29E+5	4.91E+5

As shown, the largest volumes are projected for the southeast region.

8.2.2 Results of the Regional Analysis

This section presents a discussion of the indirect unmitigated impacts of implementation of the Part 61 rule based on analysis of the above regional cases. The section is divided into three subsections as follows: long-term radiological impacts, costs and short-term radiological impacts, and other impacts.

Long-Term Radiological Impacts

A range of long-term radiological impacts for the regional case study are summarized on Table S.8.

Table S.8 Summary of Long-Term Environmental Impacts from Regional Case Study

Impact Measures	Modified Waste Spectrum 1				Waste Spectrum 2			
	Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Maximum individual intruder impacts: (mrem/yr to bone)								
100 years	3.80E+0	2.32E+1	2.73E+1	2.09E+1	5.23E+0	2.97E+1	3.50E+1	2.86E+1
500 years	4.83E-1	5.00E+0	6.19E+0	3.15E+1	6.54E-1	6.84E+0	8.50E+0	4.63E+1
Maximum population intruder impacts:								
Airborne (man-mrem/yr to bone)	1.70E+5	1.93E+4	3.22E+4	1.87E+2	1.02E+5	1.66E+4	2.80E+4	1.67E+2
Waterborne (mrem/yr to bone)	8.29E-3	3.17E-3	4.82E-3	4.36E-3	1.09E-2	4.04E-3	6.05E-3	5.78E-3
Maximum erosion impacts:								
Airborne (man-mrem/yr to bone)	3.12E+2	1.49E+2	1.42E+2	6.11E+0	3.11E+2	1.49E+2	1.42E+2	6.11E+0
Waterborne (mrem/yr to thyroid)	9.77E-1	1.18E+0	9.47E-1	5.90E-1	9.77E-1	1.18E+0	9.47E-1	5.90E-1
Maximum ground-water impacts: (mrem/yr to thyroid)								
Intruder well	6.43E+0	5.62E+0	6.84E+0	2.53E-2	7.25E-1	6.36E-1	6.73E-1	1.45E-2
Boundary well	6.02E+0	5.62E+0	6.84E+0	2.45E-2	6.52E-1	6.36E-1	6.73E-1	2.91E-3
Population well	$<10^{-9}$	1.78E+0	3.26E-1	9.40E-4	$<10^{-9}$	2.01E-1	3.20E-2	1.11E-4
Surface stream	$<10^{-9}$	8.09E-2	$<10^{-9}$	*	$<10^{-9}$	9.14E-3	$<10^{-9}$	*

*Impacts at the surface stream are not calculated for the southwest site due to the intermittent nature of the nearest stream to the site and the extreme depth to ground water.

Maximum individual intruder impacts are summarized on Table S.8 at time periods equal to 100 and 500 years following disposal facility license termination. Maximum population intruder impacts are also summarized as estimated at 100 years following license termination. Airborne impacts are presented as total exposures (in man-mrem/yr) to persons living within 50 miles of the disposal facility. Waterborne impacts are presented for an individual who is assumed to use water from a surface stream contaminated from overland flow of material released from the facility by the intruder. Maximum potential erosional impacts (to the bone) are also shown as impacts to populations for airborne releases and as impacts to an individual for waterborne releases.

In the analysis, the assumed use of grouting to stabilize the northeast site results in reduced intruder exposures relative to the southeast and midwest sites. For these latter two sites, inadvertent intruder exposures averaged over the total waste volume disposed at the sites range from about 15 to 35 mrem/yr at 100 years but drop to a few (4 to 9) mrem/yr at 500 years. The increased volume reduction associated with waste spectrum 2 results in higher overall radionuclide concentrations then for modified spectrum 1, with resulting slightly higher estimated impacts. In the analysis, no credit has been taken for improved waste forms to reduce dispersion and plant root uptake. This improved waste form would tend to reduce intruder exposures for waste spectrum 2, particularly at the southwest site.

The highest individual intruder exposures are estimated to occur at the southwest site. These exposures run at about 46 mrem/yr to bone but are still a factor of 10 less than the 500 mrem/yr limit. The increased exposure is due to the increased silt content of the site soils as well as the increased wind speeds relative to the other three sites. These impacts are believed to be very conservative, since the great depth to the water table allows disposal at much greater depths than at the other three sites--further reducing the potential for inadvertent intrusion into the more highly active waste streams.

Both types of scenarios--inadvertent intrusion and erosion--should be interpreted as hypothetical events. In particular, the erosional impacts are included as an upper bound of such impacts if significant large scale erosion did occur. Disposal facilities licensed under the Part 61 regulation would be sited to avoid such potential problems with erosion.

As shown in Table S.8 the highest exposures due to ground-water migration are to the thyroid, although in all cases the performance objectives for inadvertent intrusion and ground-water migration are met. The estimated impacts reflect the differing volumes of waste streams and corresponding radionuclide inventories within each regional facility, as well as the differing environmental characteristics of each regional site. Of the three humid regional sites, the southeast is assumed to experience the largest percolation component (PERC) as well as the quickest ground-water travel times to human access locations. In addition, the midwest and southeast site soils are assumed to have moderate retardation capabilities while the retardation capability of the northeast site soil is higher.

The southwest site is located in a semiarid area and a water balance calculation for the site indicated that essentially no precipitation falling upon the site reaches the underlying aquifer. For completeness in the analysis, however, a percolation coefficient of 1 mm was conservatively assumed for the site. The resulting estimated exposures are a few orders of magnitude less than those for the other three sites at the intruder, boundary, and population wells. The surface water body exposures are not presented for the southwest site, however. The closest water body down-gradient of the site is an intermittent stream, and in any case, the water table is located on the order of 80 meters below ground surface.

Costs and Short-Term Radiological Impacts

Costs and short-term radiological impacts are summarized in Table S.9. Included in this table are (1) potential impacts to populations (in man-mrem) from transporting waste to the regional facilities, (2) potential occupational impacts (in man-mrem) associated with processing, transporting, and disposing of waste within the region, and (3) costs. Impacts and costs are shown as total impacts and costs over the 20-year operating life of the disposal facility.

As shown, transportation impacts over 20 years range from about 420 to 1,100 man-rems, or about 21 to 55 man-rems per year. The higher estimated impacts for the southwest site are due to the greater transportation distance for the western region as compared to the other three regions (1,000 miles vs 300 to 600 miles).

Occupational impacts are listed as total impacts over 20 years for waste processing, transportation to the disposal facility, and waste disposal. Waste processing occupational exposures are presented as additional exposures to those associated with waste spectrum 1. These exposures are believed to be conservatively high, due to the conservative nature of the analysis as well as the fact that many waste generators are already compacting waste or stabilizing high activity streams to comply with existing license conditions at LLW waste disposal facilities.

Also included are the occupational exposures that are estimated to be associated with operation of a regional processing center. For waste spectrum 2, waste processing is assumed to consist of compaction of compressible waste streams by large compactor/shredders. This is not likely a cost effective operation but has been included for completeness.

As expected, the largest occupational exposures for waste disposal are those estimated for the northeast site. This is due to the assumed additional operational practices carried out at the northeast site.

Costs, including waste processing, transport, and disposal costs are also listed in Table S.9. Costs due to processing the waste by the waste generator are presented as additional costs to those associated with waste spectrum 1. For the modified spectrum 1 case, these additional costs involve stabilizing high activity waste streams at an estimated cost of $450 per m^3 of waste so stabilized, which is the approximate cost of placing the waste streams into high-integrity containers. It is expected that some of the waste streams may be stabilized by the less expensive means; however, using the high-integrity container costs

Table S.9 Summary of Costs and Short-Term Radiological Impacts for the Regional Case Study

Impact Measures*	Modified Waste Spectrum 1				Waste Spectrum 2			
	Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Transportation Population Impacts: (man-mrem)	4.16E+5	6.02E+5	6.54E+5	1.10E+6	4.02E+5	5.97E+5	6.52E+5	1.08E+6
Occupational Impacts: (man-mrem)								
Waste Process								
By Generators	-	-	-	-	+1.70E+6	+1.98E+6	+1.50E+6	+9.00E+5
Regional Center	0	0	0	0	1.81E+5	7.15E+4	1.08E+5	9.02E+4
Transportation	5.54E+6	6.92E+6	5.04E+6	4.89E+6	5.21E+6	6.43E+6	4.79E+6	4.54E+6
Waste Disposal	5.10E+6	2.96E+6	2.03E+6	2.80E+6	4.78E+6	2.81E+6	1.96E+6	1.68E+6
Waste Processing Costs: ($)								
Waste Generator	+7.28E+7	+9.89E+7	+6.63E+7	+5.22E+7	+3.47E+8	+3.95E+8	+2.92E+8	+1.91E+8
Regional Center	0	0	0	0	+5.29E+7	+2.07E+7	+3.14E+7	+2.63E+7
Waste Transportation Costs: ($)	1.45E+8	2.43E+8	2.40E+8	3.41E+8	1.32E+8	2.18E+8	2.22E+8	3.08E+8
Waste Disposal Costs: ($)								
Design & Op.	2.75E+8	2.10E+8	2.01E+8	1.89E+8	2.53E+8	2.01E+8	1.94E+8	1.86E+8
Post operational	1.26E+7	1.91E+7	1.91E+7	1.26E+7	1.26E+7	1.26E+7	1.26E+7	1.26E+7
Total	2.88E+8	2.29E+8	2.20E+8	2.02E+8	2.66E+8	2.14E+8	2.07E+8	1.99E+8
Unit ($/$m^3$)	290	214	291	278	388	285	391	405

*Costs and impacts (except for unit disposal costs) are shown as total costs and impacts over the 20-year operating life of the disposal facility.

provides an upper bound. For waste spectrum 2, stability of many of the waste streams--particularly LWR process waste streams--is provided through solidification. Costs for stabilization of other waste streams is again represented by the estimated costs for high-integrity containers. Finally, in waste spectrum 2, additional costs are incurred through compaction of compressible waste streams, both by waste generators and at a regional center.

Of these costs, the only additional waste processing costs that would be incurred through implementation of the Part 61 regulation would be through stabilization of the higher activity streams. For waste spectrum 2, these are conservatively estimated as follows:

Waste Spectrum 2	Northeast	Southeast	Midwest	Southwest
$\$(x10^8)$	2.82	3.58	2.70	1.64
$\$/m^3$	1363	1310	1390	1158

Thus, the requirement that higher activity wastes be stabilized would appear to involve additional processing costs in the following range.

	Northeast	Southeast	Midwest	Southwest
Low ($\$x10^7$)	7.3	9.9	6.6	5.2
High ($\$x10^7$)	28.2	35.8	27.0	16.4

This range is believed to be conservatively high, however. In addition, much of the above costs would be expended in any case to comply with license conditions already implemented by the states at existing disposal facilities.

Waste transportation costs range from about $130 to $240 million, depending upon the waste spectra and the region considered. The largest costs are for the southwest region, for which the reduced volume of waste relative to the other three regions is counterbalanced by the longer transportation distances.

Waste disposal costs are set out into design and operational costs and post-operational costs, where postoperational costs include costs to waste customers (over 20 years of operation) for providing for: (1) facility closure, (2) a 5-year observation and maintenance period, and (3) 100 years of institutional control. Also shown are total disposal costs as well as unit ($\$/m^3$) costs.

As shown, the most significant design and operational costs are for the northeast site, due to the assumed use of grouting to assure stabilization of wastes. The design and operational costs for the other three sites are clustered within a relatively small range.

Unit costs are seen to vary widely depending upon the assumed design and operating practices carried out at the particular disposal facility as well as the volumes of waste delivered to the facility. For example, the design and operation of the southeast site is essentially the same as the midwest facility. However, the volume of waste delivered to the midwest facility is much less than the southeast facility, while the design and operational costs are only slightly less. This is because capital costs to construct the disposal facility are much less dependent upon the volumes of waste delivered to the facility than the operating costs. Many of the same expenses to design, build, and operate the facility would be incurred whether a high or a low volume of waste was received.

Other Impacts

This section discusses indirect impacts associated with the proposed Part 61 regulation other than radiological impacts or costs. The impacts are broken down into the following subsections: Air quality (nonradiological), biota (ecology), land use, energy use, and social impacts.

Air Quality. Nonradiological impacts to air quality due to LLW management and disposal would principally arise from two sources: combustion of fossil fuels during processing, transporting, and disposing of waste and (2) particulate matter (dust) released into the air due to earth moving activities at the disposal facility. Typical combustion products would include suspended particulates, sulphur dioxide, CO_2, CO, various hydrocarbons, and various nitrogen oxides.

It is believed that implementation of the Part 61 regulation would have a relatively slight effect upon overall air quality. For example, increased waste processing such as compaction and solidification would probably result in increased combustion of fossil fuels, with correspondingly increased release of combustion products into the air. However, many waste generators are already performing such waste processing activities to reduce transportation costs or to comply with existing license conditions at disposal facilities. Moreover, waste processing activities that reduce waste volumes would tend to reduce releases of fossil fuel combustion products during transportation.

At the disposal facility, local impacts to air quality result from combustion of fossil fuels by vehicles delivering waste to the facility, by vehicles owned by facility personnel, and by heavy equipment operated at the facility. Dust could be raised by excavating, backfilling, and grading activities. However, similar types of impacts can and would be raised by many other types of small industrial concerns.

Since the Part 61 regulation emphasizes increased disposal facility stability, somewhat additional air quality impacts could result during the operating life of the disposal facility. However, such additional impacts would be felt only during the time the facility was operating. In addition, if the facility was left in an unstable condition after operation, increased longer-term air quality impacts could result due to operating machinery to repair holes in disposal cell covers, potential operation of a leachate evaporator, and so forth. Placing the facility in a more stable condition during site operations reduces the maintenance that would be required after facility closure, thus lowering longer term nonradiological air quality impacts.

Biota. The operation of a disposal facility would involve acquiring and fencing in up to a few hundred acres of land. Existing vegetation would be mostly cleared, and after waste disposal, the disposal cells would be regraded, recontoured, and probably reseeded with short-rooted local vegetation. During this process, impacts to biota could result from destruction of habitat. Similar types of impacts would result from other uses of the land which involve heavy construction. Implementation of the Part 61 rule is expected to have little effect on the potential for impacts to biota. There are already existing federal and state laws and regulations governing protection of endangered or unique flora and fauna.

Land Use. In most cases, the operation of a licensed nuclear facility by a licensee does not result in the land being permanently committed to that activity. At an LLW disposal facility, however, possible future use of the facility after it has closed is greatly influenced by the presence of the disposed waste. This does not mean that land used for LLW disposal is permanently excluded from productive use. Rather, as long as care was taken to restrict activities to those which would not involve excavating into the disposed waste or bringing contamination to the surface, there may be a number of useful purposes the facility surface may be put to. These could possibly include use of the facility for golf courses, recreational areas, or light industry.

It is difficult to assess the influence of the Part 61 regulation on land use. Depending upon the design and operation of the disposal facility and the manner in which higher activity wastes are stabilized, land use could be lower or potentially higher than without the regulation. A range in land use may be estimated, however, using the regional analysis as a guide. In the analysis land use ranges from about 160,000 m^2 (39 acres) to 370,000 m^2 (92 acres) at the regional sites, depending upon the volume of waste disposed and the disposal technology implemented. For modified spectrum 1, the total amount of land committed to LLW disposal over 20 years is estimated to be 1.1 million m^2, or about 276 acres. For waste spectrum 2, for which increased use is made of volume reduction, this land use is reduced to 775,000 m^2 or 192 acres. This includes an assumed 3-meter spacing between disposal cells but does not include other land such as administrative areas, buffer zones, onsite roads, and so forth.

Energy Use. One way in which the effects of a proposed action can be quantified is to estimate the total energy requirements associated with that action. In the analysis, incremental energy use ranged from -270,000 gal to +8,970,000 gal per region. It should be realized that there are large uncertainties in these calculations. Much of the projected increase in energy use is due to activities such as increased disposal stability or increased waste processing which by and large are already being carried out. In general, the overall tendency of the Part 61 regulation would be to increase short-term energy use but reduce long-term energy use.

Social Impacts. In general, social impacts due to promulgation of the Part 61 regulation are difficult to address. These impacts are very site-specific and would include such aspects as the effect of bringing a labor force into an area on local utilities, schools, and other services. These types of impacts are typically of most concern during the siting, construction, and operation of large facilities such as a large nuclear power plant. A low-level waste disposal facility is by comparison a very small operation, and the proposed Part 61 regulation is not expected to result in any significant incremental changes in social impacts associated with operation of LLW disposal facilities.

ATTACHMENT A. Proposed Rule 10 CFR Part 61: Licensing Requirements for land Disposal of Radioactive Waste

NUCLEAR REGULATORY COMMISSION

10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 61, 70, 73 and 170

Licensing Requirements for Land Disposal of Radioactive Waste

AGENCY: Nuclear Regulatory Commission.

ACTION: Proposed Rule.

SUMMARY: This notice invites public comment on proposed amendments to the Commission's rules to provide specific requirements for licensing the land disposal of radioactive wastes. The proposed amendments set forth performance objectives for disposal, general requirements for land disposal of radioactive waste, technical requirements for disposal of radioactive waste into near-surface disposal facilities, requirements for submitting applications for licenses authorizing such activities and procedures which the Commission will follow in the issuance of such licenses. The rule does not deal with disposal by individual licensees by burial of their own wastes. The proposed amendments also set forth provisions for consultation and participation in license reviews by State governments and Indian tribes. Further amendments are proposed governing the transfer of licensed material for disposal. The proposed requirements respond to the needs and requests of the public, Congress, industry, the states, the Commission, and other Federal agencies for codification of regulations for the dispoal of low-level radioactive waste.

DATE: Comment period expires October 22, 1981. Comments received after October 22, 1981 will be considered if it is practical to do so, but assurance of consideration cannot be given except as to comments received on or before this date.

ADDRESS: All interested persons who desire to submit written comments in connection with the proposed amendments should send them to the Secretary of the Commission, U.S. Nuclear Regulatory Commission, Washington, D.C., 20555, Attention: Docketing and Service Branch. Copies of comments received on the proposed amendments may be examined in the Commission's Public Document Room at 1717 H Street NW., Washington, D.C.

FOR FURTHER INFORMATION CONTACT: R. Dale Smith, Chief, Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, telephone (301) 427-4433.

SUPPLEMENTARY INFORMATION:

I. Description of the Proposed Action

The U.S. Nuclear Regulatory Commission proposes to add to its rules in 10 CFR a new Part 61 to provide licensing procedures, performance objectives, and technical criteria for licensing facilities for the land disposal of radioactive waste. Specifically, the regulations would establish performance objectives for land disposal of waste; technical requirements for the siting, design, operations, and closure activities for a near surface disposal facility; technical requirements concerning the waste form that waste generators must meet for the land disposal of waste; classification of waste; institutional requirements; and administrative and procedural requirements for licensing a disposal facility. Amendments to other parts of 10 CFR are proposed to govern the certification and use of shipping manifests to track waste shipments and clarify, but not substantially modify, the requirements of existing regulations. Specific requirements for licensing facilities for the disposal of radioactive wastes by alternative land disposal methods will be proposed for Part 61 in subsequent rulemakings. Disposal of radioactive wastes by an individual licensee will continue to be governed by 10 CFR Part 20.

Part 61 defines which wastes are acceptable for disposal by near-surface disposal methods (and which wastes are not acceptable and must be disposed of by other methods). It also sets out the administrative and procedural requirements for licensing a facility for the land disposal of waste.

II. Need for the Proposed Action

Current general regulations for licensing materials do not contain any technical standards or criteria for the disposal of licensed materials. However, the need for comprehensive, national standards and technical criteria for the disposal of radioactive waste is well documented. The Commission has undertaken a program to establish such standards and criteria through this proposed rulemaking action.

III. Background

The Commission has had a program underway for several years to develop regulations and other guidance for the management and disposal of low-level waste (LLW). On October 25, 1978, the Commission published an Advance Notice of Proposed Rulemaking (43 FR 49811) regarding the development of specific regulations for the disposal of LLW. The development of these regulations was in response to needs and requests expressed by the public, the Congress, industry, the States, the Commission, and other Federal agencies for codification of regulations for the disposal of LLW. To provide guidance and support for developing the new regulation, 10 CFR Part 61, the Commission has prepared a draft environmental impact statement (EIS) NUREG-0782.[1] The statement is not a generic EIS on the disposal of LLW. Rather, it is a decision document that has been prepared to provide a basis for decisions on the performance objectives and technical and financial criteria set out in Part 61. As part of the process to scope the form and content of the EIS and the proposed regulation, the advance notice asked for advice, recommendations, and comments on the scope and content of the EIS and the regulation. As a part of this advance notice, the Commission announced its intention to:

- Develop technical criteria and standards for the disposal of LLW by shallow land burial and alternative disposal methods.
- Prepare a supporting EIS for the regulation.
- Coordinate development of technical criteria and standards for shallow land burial and alternative disposal methods with requirements for the classification of waste (Define the concentrations and quantities of waste acceptable for disposal by various disposal methods).

[1] Single copies of this report will be available free upon publication to the extent of supply and may be obtained by written request to the Director, Division of Technical Information and Document Control, Washington, D.C. 20555 Copies will also be made available for inspection or copying for a fee at the NRC Public Document Room, 1717 H Street NW., Washington, D.C.

The Commission received a total of 36 responses from the public on the advance notice. These comments have been docketed (Docket No. PR-61) and may be examined in the Commission's Public Document Room located at 1717 H Street NW., Washington, D.C. A detailed analysis by the Commission of the public responses received may also be examined in the Public Document Room. The respondents to the advance notice strongly supported the Commission's development of specific criteria and standards for the disposal of low-level waste. There was also support among the commenters that an overall EIS should be prepared to provide an essential part of the informational and decisional base for the development of the criteria and standards for the rulemaking action. However, the commenters were divided on the form and structure of the criteria and standards. Some commenters stated that the criteria and standards should be minimal and basic and should emphasize the performance objectives to be met by low-level waste disposal facilities. Others suggested the criteria and standards should be specific and detailed. Many commenters also stated that as part of the development of LLW disposal standards and criteria a system was needed for classifying or segregating the waste based on hazard.

A number of comments were received on the Commission's questions regarding alternative disposal methods to shallow land burial. Although the comments in this area were mixed, the most often expressed opinion was that primary consideration should be given to developing requirements for shallow land burial and emplacement of waste into mined cavities. Disposal of wastes in ocean waters was given the lowest priority. Four commenters felt there was no need to establish a priority list of the alternative disposal methods to shallow land burial. The most often expressed disadvantage of any alternative method was the potential for increased cost. Approximately 60 percent of the respondents suggested other potentially viable methods for low-level waste treatment and/or disposal. The methods most frequently mentioned were volume reduction and other advanced processing techniques.

The comments received by the Commission on the advance notice were used by the Commission in scoping the form and content of the EIS and the regulation. For this scoping process, the Commission also considered a numbr of other sources, including:

- The results of program studies and other technical data on LLW management and disposal;
- Licensing experience with current LLW disposal sites and current LLW management techniques;
- Programs by the Environmental Protection Agency (EPA) to develop criteria and standards for LLW management and regulations for disposal of nonradio-active solid and chemically hazardous wastes;
- Recommendations of the Interagency Review Group on Nuclear Waste Management;
- Natural Resources Defense Council (NRDC) Petition for Rulemaking (PRM 20-7);
- Discussions with industry and public interest groups, State and Federal agencies, and others;
- Recommendations from the State Planning Council; and
- Public Law 96-573, "Low-Level Radioactive Waste Policy Act."

On February 28, 1980, the Commission also published a Notice of Availability of a preliminary draft regulation, dated November 5, 1979, announcing availability of the draft for public review and comment to help ensure wide distribution and early public review and comment (45 FR 13104). Copies of this draft regulation were distributed to all of the States. The comments received in response have been docketed (Docket No. PR-61) and may be examined in the Commission's Public Document Room located at 1717 H Street NW., Washington, D.C.

During the summer and fall of 1980, the Commission also sponsored 4 regional workshops to provide an opportunity for open dialogue among representatives of the States, public interest groups, the industry, and others on the issues to be addressed through the Part 61 rulemaking. One workshop was conducted by the Southern States Energy Board for the southeast region, a second by the Western States Energy Board for the west, a third by the Midwestern Regional Office of the Council of State Governments for the central region and midwest, and a fourth by the New England Regional Commission for the northeast. These workshops were particularly useful in formulating our positions on the more judgmental aspects of the rule and underlying assumptions (such as the length of time we should assume that active governmental controls could reasonably be relied on). A copy of the full transcript for each meeting and a summary report documenting the collective views of the participants has been placed in the docket for this rulemaking (Docket No PR-61) and may be examined at the Commission's Public Document Room located at 1717 H Street NW., Washington, D.C.

IV. Purpose and Scope of Part 61

It is the purpose of Part 61 to establish technical criteria and procedures for licensing facilities for the land disposal of radioactive wastes. Part 61 will not apply to alternative disposal methods such as deep space or ocean disposal. It is not practicable to develop one regulation dealing with such a wide variety in disposal technologies. Requirements for ocean disposal are a responsibility of the EPA. Space disposal, although technically feasible, is not developed to the point of routine, economic application.

The recently enacted Low-Level Radioactive Waste Policy Act (Pub. L. 96-573) sets forth a traditional definition of "low-level radioactive waste," i.e., radioactive waste not classified either as high-level radioactive waste, transuranic waste, spent nuclear fuel, or uranium mill tailings (byproduct material as defined in section 11 e.(2) of the Atomic Energy Act of 1954). While Part 61 is intended to deal with the disposal of most wastes included in this definition, the waste classification scheme that forms the basis for Part 61 has identified some "low level radioactive wastes" that are not suitable for disposal by the means that Part 61 provides, and alternative methods will have to be used. Therefore, the term "low-level radioactive waste" is not used in Part 61. Reference is made to "waste" and "radioactive wastes" which, within the context of Part 61, refers to those wastes that are acceptable for disposal under the provisions of Part 61.

This proposed regulation includes overall performance objectives expected in any type of land disposal and technical requirements for the disposal of waste near the surface. The technical requirements for disposal are set forth for disposal site characteristics, disposal site design and near-surface disposal facility operations, classification and characteristics of wastes, and institutional control and surveillance.

V. Summary of Rule

The following sections provide a discussion of the major provisions of Part 61.

A. Performance Objectives Versus Prescriptive Requirements

In developing Part 61, the Commission has considered two basic approaches: a performance objective approach and a prescriptive approach. A regulation oriented toward performance objectives would establish the overall objectives to be achieved in waste disposal and would leave flexibility as to how the objectives would be achieved.

In the latter approach, specific detailed requirements for design and operation of a land disposal facility would be set out in the regulations. Prescriptive standards would specify the particular practices, designs, or methods to be employed—for example, the thichness of the cover material (the cap) over a land disposal trench, or the maximum slope of the trench walls.

Setting of prescriptive standards requires a considerable amount of detailed knowledge about potential designs, techniques, and procedures for disposing of wastes in order to prescribe which designs, techniques, and procedures are among the best and would assume that the state of art in waste disposal is developed to the point where there are clear choices to be made among all the potential approaches.

A combination of approaches has been chosen for Part 61. Overall performance objectives are stated and the applicant has flexibility in choosing design features and operating practices to achieve these objectives. There are some prescriptive requirements that have been judged necessary in light of past operating experience with disposal facilities. To the extent practicable, these requirements are stated as minimum criteria to afford some flexibility in meeting them.

B. Development of Performance Objectives

With respect to the performance objectives, the Commission's overall goal is to assure protection of the public health and safety. In considering radioactive waste disposal, attainment of this goal would appear to fall into two time frames: the short-term operational phase and the long term after operations cease.

In the short term, the concern is for protection of workers and the general population during operation of a disposal facility.

Protection of the public health and safety over the long term is most important and long-term performance of the land disposal facility after operations cease should be given greater emphasis than short-term considerations and conveniences. It is therefore at the time of the land disposal facility closure that greatest reliance will be placed on the disposal site characteristics and design as well as the waste characteristics to assure protection of the public health and safety without the need for continued active care and maintenance.

Assuring safety over the long term involves three considerations: (1) protection of individuals from inadvertent intrusion into the site and coming in contact with the waste at some point in the future; (2) protection of the general public from potential releases to the environment; and (3) stability of the disposed waste and the site to eliminate the need for ongoing maintenance of the site following closure.

Safety During Operations. The short-term performance objective included in Subpart C of Part 61 will be to assure that the disposal facility will be operated in conformance with the same Commission standards for radiation protection set out in 10 CFR Part 20 that are applied to all Commission licensees for protection of workers (See § 61.43.)

Protection of the Inadvertent Intruder. The Commission believes that intentional intrusion into the land disposal facility (e.g., an archaeologist reclaiming artifacts) cannot reasonably be protected against. However, after the land disposal facility closes, and after active institutional control and surveillance over the disposal site have been removed, one or a few individuals could inadvertently disturb waste in the disposal site through activities such as construction of a house or by farming.

Actual intrusion into the waste may never occur; but, for purposes of Part 61, it has been assumed that intrusion could occur, in which case the one or few such individuals should not receive an unacceptable radiation exposure. The Commission is applying a 500 mrem/yr maximum individual exposure limit for this unusual case. This limit is based on ICRP recommendations for dose limits to individuals and is a level that is recognized as providing adequate protection. Since only one, or at most a few, persons would be involved, it is not necessary to consider a population dose. This limit is then used to determine the allowable concentrations of nuclides in each class of waste. (See § 61.42.)

Protection of the Environment. The primary long-term pathway of release of radioactivity from near-surface disposal involves radionuclide contamination of and transport through the ground water. Presently there exists no specific numerical standard for protection of the ground water. The Environmental Protection Agency (EPA), under its generally applicable environmental standards-setting authority, has responsibility to prepare a standard that will set limits for releases of radioactivity to the general environment from disposal facilities. After examining other existing standards, the Commission does not anticipate that the standard will be much higher than the standards already established for releases to the environment from fuel cycle facilities set out in 40 CFR Part 190 (25 mrem/yr whole-body exposure). Also, the standard will probably not be any lower than the limits established in 40 CFR Part 141 for concentrations of radioactivity in drinking water (4 mrem/yr whole body exposure). As a part of the EIS for Part 61, the Commission analyzed a range of limits from 1 mrem/yr to 25 mrem/yr applied at various locations at and in the vicinity of a disposal facility. Based on the numerical limits already set for existing standards and this analysis, the Commission has selected an objective that requires that any movement of radioactivity not result in calculated doses exceeding 25 mrem/yr to an individual at the site boundary or cause the EPA Drinking Water Standards (40 CFR Part 141) to be exceeded at the nearest public drinking water supply (See § 61.41). When EPA standards are effective, licensees will have to comply with them. Because these standards are specific to land disposal of radioactive waste, they are included in Part 61 rather than 10 CFR Part 20.

C. Minimum Technical Requirements

To help assure that the performance objective will be met, minimum requirements will be placed on the various parts of an overall disposal "system".

The principal parts of an overall disposal system that are readily identifiable and will be addressed in the minimum technical requirements are:

- The characteristics of the disposal site into which the waste is placed;
- The method by which the disposal site is designed, the land disposal facility constructed, the waste emplaced, and the disposal site closed;
- The characteristics of the waste; and
- The degree and length of institutional control, surveillance, and monitoring of the disposal site after closure.

Disposal Site Suitability Requirements. A wide range of locations are potentially available for use as a near-surface disposal facility ranging from the humid east to the arid west. The approach the Commission has followed in establishing the disposal site suitability requirements has been to establish a common-sense base of disposal site evaluation factors that can be consistently applied throughout the country. The requirements would essentially eliminate certain limited areas from consideration because of undesirable characteristics but would leave large areas in each region where acceptable sites could be found (see § 61.50). The requirements are intended to eliminate, to the extent practicable, those areas with certain characteristics that are known to lead to or have high potential to lead to problems over the long term (e.g., flooding or rapid erosion of the site). These disposal site characteristics include:

(1) Complexity—The disposal site must be capable of being investigated and analyzed. If the disposal site cannot be characterized, prediction of potential long-term impacts is not possible.

(2) Potential Land and Resource Use—The disposal site should not have any extensive natural resources beneath it or have such high potential for other subsequent uses of the land that immediate intrusion into the disposal site after active institutional controls are removed is likely.

(3) Surface Water—Areas with large surface water sources or high potential for flooding should be avoided to reduce the greater potential for migration that large quantities of water present.

(4) Ground water—Ground water intrusion into the disposal units should be avoided to reduce the potential for leaching of waste and subsequent migration.

(5) Stability—Stability of the disposal site over the long term is important in helping assure continued site integrity and in reducing the potential for migration and transport of waste to offsite areas.

Disposal Site Design, Land Disposal Facility Operation, and Disposal Site Closure Requirements. The specific requirements for design, operation, and closure of a near-surface disposal facility are directed at achieving long-term stability of the disposed waste and the disposal site so that, after closure, the need for ongoing active maintenance is eliminated and only minor custodial care, surveillance, and monitoring are required. (See § 61.51.) Other requirements are directed at enhancing natural disposal site characteristics by directing surface water away from disposal units, reducing infiltration of precipitation into disposal units, and reducing the potential for erosion, leading to an acceptable condition for disposal site closure.

Specific design requirements are set out relating to assuring protection of an inadvertent intruder from exposure to higher concentration wastes. Such wastes, defined by § 61.55, must be disposed of at greater depths (i.e., a minimum 5 meters below grade) or with equivalent natural or engineering barriers to reduce radiation exposure and further minimize the potential that an individual might inadvertently come in contact with the waste. In addition, a specific provision requires segregation of the lower activity compressible waste from the higher activity wastes and separate disposal. Higher activity wastes are subject to the structural stability requirements of § 61.55(b). Requirements are also established on environmental monitoring (§ 61.53).

Waste Characteristics and Classification. A cornerstone of the system to control the migration of radionuclides offsite is stability—stability of the waste and of the disposal site so that once emplaced and covered, the access of water to the waste can be eliminated or minimized. Thus, a basic requirement on waste is that it should be stable, that is, it should maintain its configuration and consistency under the conditions if would be exposed to after disposal. This stability should last long enough for the radioisotopes to decay to levels where they are no longer of concern from the migration standpoint.

While stability is a necessary characteristic for waste that has a potential for migration, studies have shown that much of the waste being disposed of does not contain sufficient amounts of radionuclides to be of concern from the migration standpoint. However, these same wastes, such as ordinary trash-type wastes tend to be unstable. It is obvious that if these wastes were disposed of with higher activity waste, their deterioration could lead to failure of the system and permit water to penetrate the disposal site and cause problems with the higher activity wastes. The choice, then, is either to require these less hazardous wastes to meet stability requirements or to segregate them from the more hazardous waste. Since stability requirements for low activity wastes would probably require expensive processing, segregation appears to have a cost/benefit advantage in spite of possible increased costs of disposal site stabilization.

A simple waste classification scheme has been devised and incorporated into Part 61. The scheme is based on the role that the waste plays in the assurance that the performance objectives of protecting persons from radiation from waste will be met.

The first categorization of waste is to identify those wastes that do not have to meet the stability requirements and that will be segregated at the disposal site. These wastes, called Class A segregated wastes, are defined in § 61.55 in terms of the maximum allowable concentration of certain isotopes and certain minimum requirements on waste form that are necessary for safe handling. The second category is for waste that requires stability, Class B stable waste, and is defined in terms of allowable concentrations of isotopes and requirements for a stable waste form as well as the minimum handling requirements.

There are concentrations of certain isotopes that will require protection against inadvertent intrusion after institutional controls have lapsed. These concentrations have been determined by analysis of the exposure to humans from the postulated intrusion of an individual after the 100 year period of institutional control. Any waste with concentrations of these isotopes that would cause an exposure greater than 500 millirem must be protected from intrusion by deeper burial or some other barrier. Wastes requiring such protection are identified as Class C intruder wastes.

The waste classification section also places upper limits on concentrations of isotopes in any class of waste. Wastes containing higher concentrations are generally excluded from near-surface disposal. Part 61 provides for special consideration by the Commission of proposed disposal methods on a case-by-case basis for wastes that exceed these values.

For most of the alpha emitting transuranic nuclides, the maximum allowable concentrations were calculated to be in the range of 10 nanocuries per gram currently imposed by disposal facilities. These calculations were conservatively based, in that they did not allow credit for dilution by other wastes. If this factor were changed, the values would increase somewhat. A decision was made not to recalculate in order to come up with higher values. This decision is based on two factors. First, in the spirit of the ALARA (as Low as Reasonably Achievable) concept, the lower value of 10 nCi/g has been demonstrated as an achievable concentration to control the disposal of transuranic nuclides. This value has been imposed by the Department of Energy for some eleven years and by most of the commercial disposal site operators for nearly that long. The last commercial site imposed the 10 nCi/g restriction in 1981. Thus, there is no need to increase the limit from the standpoint of achievability. Second, there is a tendency toward a more conservative assessment of the hazard of certain transuranic nuclides (Ref. ICRP 30) and it does not seem prudent at this time to use the higher calculated values. A value of 350 nCi/g was established for plutonium–241, since this concentration of short lived beta-emitting isotope decays to a 10 nCi/g concentration of americium=241, a longer lived alpha-emitter. At present, wastes containing transuranic nuclides in concentrations greater than 10 nCi/g are not being generaged in significant volumes.

Based on the values in Table I, and the isotopic content of various waste streams analyzed in the Environmental Impact Statement, the following waste streams would generally fall into the waste classes indicated.

Class A—Segregated Waste

PWR Ion Exchange Resin (low activity)
PWR Concentrated Liquids (low activity)
PWR Filter Sludges (low activity)
PWR Filter Cartridges (low activity)
PWR Compactible Contaminated Trash
BWR Compactible Contaminated Trash
Fuel Fabrication Compactible Trash
Fuel Fabrication Noncompactible Trash
Institutional Trash
Industrial Sealed Source Manufacturing Contaminated Trash
Industrial Low Activity Trash
Fuel Fabrication Process Waste
UF_6 Process Waste
Nuclear Medicine Waste
Biomedical Research Radiotracer Waste, Biowastes, and Contaminated Trash
Academic Institution Radioactive Radiotracer Wastes, Biowastes, and Contaminated Trash

Class B—Stable Waste

PWR Ion Exchange Resins
PWR Concentrated Liquid
PWR Filter Sludges
PWR Filter Cartridges
BWR Ion Exchange Resins
BWR Concentrated Liquids
BWR Filter Sludges
PWR Noncompactible Trash
BWR Noncompactible Trash
LWR [3] Nonfuel Reactor Components
LWR [3] Decontamination Resins
Tritium Production and Processing Waste Accelerator Targets
High Specific Activity Industrial Waste

Class C—Intruder Waste

Waste [3] from Isotope Production Facilities
Sealed [3] Sources

Note.—More recent data indicate that power reactor operation and waste processing characteristics are tending to move LWR wastes into higher classes.

The Commission has not developed a classification of waste based on total hazard. The classification is based on radiation protection considerations.

The Commission, however, has addressed other potential hazards presented by other associated components of waste (e.g., chemical and biological hazards) through te exclusion or treatment of certain chemical, physical and biological forms of waste.

The Commission recognizes the need for a "de minimis" classification of wastes, wastes that would be exempt from Part 61 and would be considered of no regulatory concern. The Commission believes, however, as the Federal Radiation Policy Council has recommended, that such exemptions should be determined on a specific waste basis. In this regard, a recent rulemaking (46 FR 16230) established such an exemption in a new § 20.306 for certain levels of tritium and carbon-14 contained in liquid scintillation and animal carcass waste. Other wastes may also readily lend themselves to treatment in this manner. The Commission will be working over the next 2 years to define these wastes and provide for additional exemptions as appropriate. Thus, Part 61 will not establish a generic "de minimis" category for waste.

D. Land Ownership of Near-Surface Disposal Facilities

Federal or State government ownership of land for disposal of waste at a land disposal facility has been a requirement in the Commission's regulations (10 CFR 20.302) since the inception of commercial disposal operations. This requirement is being continued to assure adequate control of the disposal site after closure and to reduce the potential for inadvertent intrusion. (See § 61.59.)

Although ownership by a State or the Federal Government is required before the Commission will issue a license, the Commission will consider an application when the site is privately owned if the applicant provides evidence that arrangements have been made with a State or the Federal government to assume ownership before the license is issued. The details of the arrangement may include whatever provisions the State or Federal agency considers appropriate as long as they are not inconsistent with requirements of the Commission.

E. Institutional Control

Control of access to the disposal site and use of the land following closure of the site is required to keep people from having contact with the waste and affecting the integrity of the disposal site. Active institutional controls involving periodic surveillance by the custodial agency and controlled access (e.g., maintaining a fence) cannot be relied upon indefinitely (§ 61.60 will not allow reliance on active institutional controls for more than 100 years since this is judged to be maximum time that governmental institutions should be relied on to carry out active controls.)

A monitoring program to check on continued disposal site integrity would also be carried out. Control and surveillance of the disposal site by the State or Federal land owner/custodial agency is needed to prevent an intruder from excavating, drilling wells, or performing other activities that would expose that individual or lead to possible increased migration offsite. Active controls would eventually be removed and replaced by more passive controls (e.g., government land ownership and records) which will be an inexpensive means of ensuring that knowledge of the disposal facility will be retained.

F. Financial Assurances

Given the past history at some of the existing disposal sites, one of the key concerns is assurance of adequate financial qualification on the part of the applicant to construct and operate the disposal facility and to provide adequate financial provisions for disposal site closure and postoperational activities.

Subpart E requires that the applicant be financially qualified to conduct all licensed activities during the construction and operational phases of the land disposal facility. Proof of the financial qualifications of applicants is not currently required by Parts 30 and 40. This new requirement will help assure that resources are not expended on projects without adequate backing. This requirement should minimize the potential for early default or the abandonment of the site by the operator.

Section 61.62 of the Part 61 requires the applicant to provide an acceptable form of financial surety to ensure that funds are available to perform closure and stabilization and observation until the license is transferred to the custodial agency for institutional control or terminated. The Commission has received evidence of a great deal of public interest concerning the issue of financial responsibility for closure of a disposal site. Numerous written comments were made on this portion of the draft regulation, and the issue was also raised at all four workshops held to review this regulation. Many commenters felt that the licensee should be held responsible for the full costs of closure of a disposal site and that the license should not be terminated and the land returned to the custodial government authority until the licensee has completed satisfactory closure.

The amount of surety liability required is based on cost estimates

[3] These waste streams may contain concentrations of certain isotopes that will require special assessment and Commission approval for near-surface disposal

submitted by the licensee in an approved plan for disposal site closure and stabilization. The applicant must submit a cost estimate for disposal site closure that includes consideration of inflation, increases in the amount of disturbed land, and the closure and stabilization activities that have already occurred at the disposal site. The Commission expects that the closure costs will be minimal when compared to the other life cycle costs of the disposal site because the regulation requires the licensee to perform the majority of closure and stabilization activities as an integral part of normal disposal site procedures during the operating period.

The types of surety arrangements being considered in Part 61 are similar to the Commission's recently enacted uranium mill tailings requirements (45 FR 65521). In their evaluation of various surety mechanisms, the Commission used the following criteria: (1) degree of security in obtaining funds in case the licensee defaults; (2) amount of administrative time and expense required to implement and monitor the surety; (3) problems of asset valuation posed by the mechanism; and (4) the cost of the surety mechanism. Based on this review, the Commission found the following types of surety mechanisms to be acceptable: surety bonds, cash deposits, trust funds, deposits of government securities, escrows, letters or lines of credit, and a combination of these mechanisms or such other types of arrangements as may be approved by the Commission. The Commission found that self-insurance for a private sector applicant was not an acceptable surety mechanism.

Section 61.63 requires the applicant to provide evidence to the Commission that a legally binding arrangement, such as a lease, exists between the applicant and the party holding title to the disposal site. Such a binding arrangement would delineate financial responsibility for the active institutional control period, which is not expected to exceed 100 years. The Commission feels that this regulatory approach is required so that all necessary activities following licensing transfer, such as surveillance, monitoring, and custodial activities, will be performed promptly and in a manner that will protect the public health and safety.

Currently the Commission lacks authority to require land disposal facility licensees to provide financial responsibility for activities occurring after the original licensee's responsibilities have ceased and the license has been transferred to another party. The Commission is considering legislation proposals that would give the Commission the authority to require financial assurances of land disposal facility licensees for the active institutional control period. In the meantime, the Commission feels that the most appropriate regulatory approach is to require an applicant to submit evidence of a binding arrangement.

Manifest Tracking System. Section 20.311 of Part 20 establishes the requirements for a manifest tracking system for wastes. The system will address the need for more complete information on the classification and characteristics of the waste, for improved accountability of wastes, and for a better data base. The EPA has recently instituted a manifest tracking system for hazardous wastes. The General Accounting Office (GAO) noted the need for improvements in these two areas in its report entitled "The Problem of Disposing of Nuclear Low-Level Waste: Where Do We Go from Here?", published March 31, 1980. The GAO recommended that the Commission "Determine who the generators of low-level are in both the Agreement and non-Agreement States and how much waste each licensee is generating" and "Establish a method to track waste from the point of generation to the point of disposal." Improving the data base on waste will improve the credibility of decisionmakers, enable better planning for inspections and emergencies, enhance projection of future waste generation, and help in site specific analyses and planning. The information on waste classification and characteristics is necessary for proper handling and disposal at the land disposal facility (e.g., which waste requires intruder barriers).

Licensees who ship under existing regulations are required to prepare and forward shipping manifests that comply with DOT regulations. The proposed manifest content requirements in § 20.311 are somewhat more comprehensive but compatible with DOT requirements. The waste generator must be specifically identified. The information requirements concerning the waste itself are somewhat more extensive and geared to information needed for disposal, not just transportation and handling. More explicit information on chemical content and composition and solidification agents is required. Licensees are required to comply with and certify compliance with waste form requirements of Part 61. This latter requirement stems solely from the technical requirements for disposal and is therefore new. The land disposal facility licensee must record data on the condition of the waste itself and document and certify receipt, handling, repackaging, storage, and disposal.

The use of the manifests as provided in § 20.311 provides a tracking system that is inspectable. Section 20.311 requires the shipper to provide copies of the manifest to precede and accompany shipments and investigation if notification of receipt or disposal is not received. The responsibility for tracking shipments is with the shipper who may be the generator, a service company who collects, stores, and delivers the waste, or an intermediate processor. A crosscheck is provided to ensure that delayed or missing shipments are investigated by requiring land disposal facility operators to periodically match advance copies of manifests to those for shipments actually received.

G. Life Cycle of a Typical Land Disposal Facility

The life of a typical facility can be broken into 5 phases: preoperational, operational, closure, postclosure observation, and institutional control. The following discussion considers each phase separately. The applicant's activities and procedural requirements as established by this proposed rulemaking are included.

Preoperational Phase. The preoperational phase consists of two parts: disposal site selection and characterization and licensing. The disposal site selection and characterization fall into the data gathering and planning phase. This is the phase in which the applicant selects a region of interest and searches for a number of possible disposal sites (a slate of candidate disposal sites), using reconnaissance-level information. The applicant then narrows the possible disposal sites down to one. After a proposed disposal site has been selected, based upon reconnaissance-level information, the applicant begins a detailed investigation (geology, depth to ground-water table, amount of rainfall, etc.) of the proposed disposal site. The applicant also initiates the preoperational monitoring program.

The applicant prepares an application for the land disposal facility following Subpart B. The applicant also prepares an environmental report. Of particular importance to this application are the performance objectives and technical requirements discussed earlier and the preliminary site closure plan, arrangements concerning land ownership and associated responsibilities, and financial assurance.

Licensing activities begin when the applicant files the application. The application is reviewed for completeness and acceptability in accordance with new Paragraph 2.101(b)(2), prior to docketing. Notice of receipt of the tendered application is to be published in the Federal Register. The Commission notifies state, local and tribal officials and begins to coordinate with these officials. Once docketed, the application is again noticed in the Federal Register and the application and environmental report widely distributed. An opportunity for interested parties to request a hearing is provided pursuant to 10 CFR 2.105. Application fees are paid in accordance with 10 CFR Part 170.

The regulatory review period follows. The applicant continues any disposal site studies and the preoperational observation and monitoring. The applicant also responds to informtional requests. Section 61.3 requires that construction not begin until a decision is made to issue the license. The application and environmental report are updated if necessary.

The Commission reviews the application and the accompanying environmental report. The Commission requests additional information if necessary. The Commission prepares a draft environmental impact statement (DEIS). If hearings are requested, an Atomic Safety and Licensing Board (ASLB) is appointed. After the Commission's review is completed and documented and the EIS and any hearings completed, and the Commissioners have approved, the Director issues the license or denies the application in accordance with the criteria in § 61.23 and any decision rendered by the Licensing or Appeals Board. Hearings, if any, would be held in accordance with existing rules in 10 CFR Part 2. An Atomic Safety and Licensing Appeal Board and/or the Commission may review the findings of the ASLB or the ASLB findings may be appealed to these next levels and to the courts. Upon resolution of the hearings, reviews, and appeals, and the Commissioners have approved, the Director takes final action to issue or deny and publishes a notice in the Federal Register. If the ownership of the land has not been transferred to the State or Federal government, transfer would now take place. If the license is issued, it is subject to the general license condition in § 61.24 and to specific conditions as required.

If no hearings have been requested, and the Commissioners approve, the Commission publishes a notice of the issuance in the Federal Register in accordance with § 2.106, and the Director takes final action to issue or deny the license.

State and Indian tribes may participate in the Commission's license review process to aid the Commission in its review. Subpart F of the proposed Part 61 addresses such participation, which is in addition to participation as already provided in Parts 2 and 51.

Examples of the forms that State and Tribal participation may take include:

(1) Development of technical data, including, but not limited to, socioeconomic, hydrological, geological, environmental, or land use data for incorporation into the Commission's environmental impact statement on the application or other analyses.

(2) Development of public participation mechanisms to be included in the licensing process.

(3) Provision of a technical data base to provide verification to the Commission for materials presented in the license application.

(4) Exchange of State and Commission staff for cooperative review.

Operational Phase. After issuance of a license by the Commission the land disposal facility is constructed and waste receipt and disposal operations start. At intervals specified in the license, (the normal term for materials licenses is currently 5 years) the licensee would be required to submit a license renewal application (§ 61.27). At this time, the disposal site closure plan and funding requirements would be updated and financial arrangements for assurance of adequate funding reviewed. A public hearing would be offered. The licensee may also apply for amendments to the license (§ 61.26).

Disposal Site Closure Phase. As the disposal site becomes filled, time for disposal site closure approaches. Prior to closure, the licensee would submit a final closure plan for review and approval (§ 61.28). A public hearing would be offered. Upon approval, the licensee implements the plan. This would consist of decontamination and dismantlement, as appropriate, of buildings. Final disposal site contouring and preparation is performed. The licensee should work toward closure during the entire operational phase so that disposal site closure would not involve a major task.

Postclosure Observation and Maintenance. Implementation of the closure plan would be followed by a period of postclosure observation and maintenance on the part of the licensee, in which the licensee's monitoring and maintenance programs would continue (§ 61.29). This period is expected to last about 5 years to help assure that the disposal site is in a stable condition so that only minor custodial care, surveillance, and monitoring by the custodial agency are required. When the disposal site has reached a stable condition, the licensee may prepare and submit an application for transfer of the license. A public hearing would be offered. Among other things, the licensee must provide reasonable assurance that the site meets all performance objectives under Subpart C, and the Commission must find that the State or Federal agency responsible for postclosure care of the site is prepared to assume these responsibilities. As a condition for assuming these responsibilities, a State may require the licensee to comply with requirements of its own, as long as State's requirements are not inconsistent with the requirements of the Commission. Upon a satisfactory finding, the license will be transferred to the Federal or State custodial agency to cover their activities during the active institutional control period (§ 61.30).

Institutional Control Board. During the institutional control period, which for purposes of Part 61, the Commission assumes to be not more than 100 years, the custodial agency carries out a program of monitoring to assure continued satisfactory site performance and physical surveillance to keep people off the site and carries out minor custodial activities at the site. As a part of the license termination, the licensee is required to place records of the disposal facility with local, State, and Federal agencies. These records along with restrictions on the property deed and trench markers should help minimize disturbance of the disposal site. These latter mechanisms are those that would continue after the institutional control period. At the end of the necessary institutional control period, the license may be terminated (§ 61.31).

H. Other Considerations

Application to Existing Sites. Many of the operational provisions and waste characteristics requirements proposed in this rulemaking are in effect at the existing disposal facilities. Although nearly all disposal at existing facilities is carried out under State licenses, it would be the Commission's intent that in the future all disposal would be expected to comply with the provisions of Part 61. Existing disposal facilities should have no difficulty in complying with the waste classification and characteristics, manifest requirements, and the minimum requirements dealing with design and operations.

environmental monitoring, closure, post-closure observation, and institutional control. Where existing operating sites have difficulty meeting any of the criteria, the Commission will consider the matter on a case by case basis.

Naturally Occurring and Accelerator-Produced Radionuclides in Waste. Although the Commission has no direct statutory authority over naturally occurring and accelerator-produced radionuclides the evaluation of any specific disposal site will include consideration of the total impacts from all waste disposed of at the disposal site, including byproduct, source, special nuclear material, and naturally occurring and accelerator-produced material. Specific concentration limits for the disposal of important naturally occurring and accelerator-produced nuclides will be included in the planned regulatory guide on the classification of waste.

Paperwork Reduction Act. As required by Pub. L. 96-511, this proposed rule will be submitted to the Office of Management and Budget for clearance of the reporting/recordkeeping/application requirements.

Regulatory Flexibility Act. Based upon the information available at this stage of this rulemaking proceeding and in accordance with the Regulatory Flexibility Act of 1980, 5 U.S.C. 605(b), the Commission hereby certifies that this rulemaking will not, if promulgated, have a significant economic impact upon a substantial number of small entities.

The Regulatory Flexibility Act (Public Law 96-345) was signed into law in September 1980. The Act's principal objective is to make certain that Federal agencies try, where possible, to fit regulatory requirements to the scale of the affected activity. Significant economic impacts on a substantial number of small entities is a major concern. The proposed Part 61 and accompanying rule changes will potentially impact a significant number of persons licensed by the Commission and the Agreement States. The following discussion addresses the analyses required by the Act and briefly describes the impacts and how the interests of the small entities were considered in developing this proposed rule. The draft EIS for Part 61 provides additional background information and analysis of the impacts of this rulemaking action.

The need for standards to govern the disposal of radioactive wastes and new regulations to implement these standards is discussed in detail in the draft EIS.

Some provisions of the proposed rulemaking will apply to all Commission licensees who transfer radioactive waste for disposal on land. The Commission has approximately 9,000 licensees. All but a few hundred are small entities. Types of small entities that may be impacted include physicians, hospitals, medical and clinical laboratories, colleges and universities, waste collection companies, small industrial operations, and waste disposal site operators. Exact numbers of impacted entities are not available. Based on a 1979 survey of Commission licensees, less than one quarter of the licensees should be affected on a regular basis.

The reporting, recordkeeping, and other requirements with which licensees must comply in the proposed rule impose only a minor incremental burden and will result in better accountability of wastes and improvements in disposal of wastes. The reporting requirements are directed primarily at disposal site operators. Currently only two firms hold this type of license. In the foreseeable future it is not anticipated that the number of this type of licensee will reach ten. The requirements are comparable to existing requirements or requirements that would be imposed in specific licenses for site operation. All licensees transferring waste would be required to investigate and file reports if shipments are lost. (See proposed § 20.311 of 10 CFR Part 20.) Existing regulations have similar but more specific reporting requirements for lost radioactive materials. All licensees transferring waste are also required to prepare complete shipping manifests. The user and radiation safety personnel currently preparing wastes for shipment will have to spend some additional time preparing manifests and tracking shipments. Licensees are already required to keep records of transfers and certain disposals.

Compliance with the waste classification and characteristics requirements is required of all licensees who transfer waste for land disposal. The need for and impacts of compliance with waste criteria are addressed in the draft EIS. The types of impacts that the rule changes may have include additional waste treatment and processing, use of containers to meet waste form requirements, new labels for packages, and higher disposal costs in some cases to cover, for example, the addition of intruder barriers when required. Based on the analysis in the Draft EIS, it appears that very few small entities generate radioactive waste that would be subject to these requirements.

Federal rules that overlap the proposed rule are primarily those of the Department of Transportation (DOT). The Commission is not aware of any rules that duplicate or conflict with the proposed rule except that reports to the Environment Protection Agency on effluent releases and broker activities required by "Superfund" registration may be duplicative. The Commission would particularly welcome comments on how to minimize duplication with "Superfund" requirements. The Commission and DOT have an established working relationship implemented through a formal Memorandum of Understanding. The rule itself acknowledges the need to comply with DOT rules, and the Commission currently inspects licensees for compliance with DOT requirements. The manifest required by this rulemaking is consistent with DOT requirements, and the same document will be used to meet requirements of both agencies. The waste form and packaging requirements are in addition to and compatible with DOT rules.

The Regulatory Flexibility Act also requires discussion of alternatives to the proposed rule. The recordkeeping and reporting requirements impose such a minor incremental burden that no relief or exemption was considered. They are, in fact, minor modifications of existing rules and practices. Further, since the small entities account for a significant percentage of the volume of waste generated, it is important that all licensees participate in the manifest tracking system. The waste classification and characteristics portion of the rule does provide some relief from compliance for waste produced by the small entities. Where radiological hazard permits, segregated disposal has been provided as an option to complying with more restrictive waste acceptance requirements. The rule is a combination of performance and prescriptive requirements, as discussed earlier. Exemption from coverage is feasible when the radiological hazard of the wastes permits. The exemption of less hazardous wastes on a specific waste basis by separate rulemaking efforts was discussed previously. (See de minimis discussion in Section V.C.)

The economic costs of the rule to small entities have not been quantified. The incremental burdens are judged small and have been addressed qualitatively in this summary and in the EIS. The rulemaking should not affect economic factors such as employment, business viability, or ability for affected entities to compete.

The requirements in waste disposal practices are judged to significantly outweigh the small economic impact on small entities. However, the Commission is seeking comments and suggested modifications because of the widely differing conditions under which small entities operate.

Any small entity subject to this regulation who determines that because of its size, it is likely to bear disproportionate adverse economic impact should apprise the Commission in a comment that indicates:

(1) The size of their business and how the proposed regulations would result in a significant economic burden upon them as compared to larger organizations in the same business community;

(2) How the proposed regulations could be modified to take into account their differing needs or capabilities;

(3) The benefits that would accrue, or the detriments that would be avoided, if the proposed regulations were modified as suggested by the commenter; and

(4) How the proposed regulations, as modified, would still adequately protect the public health and safety.

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and section 553 of title 5 of the United States Code, notice is hereby given that adoption of a new 10 CFR Part 61 and the following amendments to 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 70, 73 and 170 is contemplated.

A new Part 61 is added to 10 CFR to read as follows:

PART 61—LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE

Authority. Secs. 53, 57d, 62, 63, 65, 81, 161b., i., o., 182, 183, Pub. L.83-703, as amended, 68 Stat., 930, 932, 933, 935, 948, 950, 953, 954, as amended (42 U.S.C. 2073, 2077, 2092, 2093, 2095, 2111, 2201, 2232, 2233); Secs. 202, 206, Pub. L. 93-438, 88 Stat. 1244, 1246 (42 U.S.C. 5842, 5846); Sec. 14, Pub. L. 95-601 (42 U.S.C. 2021a). For the purposes of Sec. 223, 68 Stat. 958, as amended, 42 U.S.C. 2273, Table 5, §§ 61.55, 61.56 issued under Sec. 161b, 68 Stat 948; §§ 61.3, 61.10 through 61.17, 61.24, 61.61 through 61.63, and 61.80 issued under Sec. 161o., 68 Stat. 950, as amended (42 U.S.C. 2201)

Subpart A—General Provisions

§ 61.1 Purpose and scope.

(a) The regulations in this part establish, for land disposal of radioactive waste, the procedures and criteria for the issuance, and terms and conditions upon which the Commission issues licenses, for the disposal for others of radioactive wastes containing byproduct, source and special nuclear material. Disposal of waste by an individual licensee is set forth in Part 20 of this chapter.

(b) Except as provided in § 61.6 "Exemptions" and in Part 150 of this chapter, the regulations in this part apply to all persons in the United States. The regulations in this part do not apply to the disposal of high-level waste as provided for in Part 60 of this chapter or byproduct material (as defined in § 40.4(a-1)) as provided for in Part 40 of this chapter and licensed material as provided for in Part 20.

§ 61.2 Definitions.

As used in this part:

"Active maintenance" means any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives in §§ 61.41 and 61.42 are met. Such active maintenance includes ongoing activities such as the pumping and treatment of water from a disposal unit or one-time measures such as replacement of a disposal unit cover. Active maintenance does not include custodial activities such as repair of fencing, repair or replacement of monitoring equipment, revegatation, minor additions to soil cover, minor repair of disposal unit covers, and general disposal site upkeep such as mowing grass.

"Buffer zone" is a portion of the disposal site that is controlled by the licensee and that lies between the disposal units and the boundary of the site.

"Chelating agent" means a chemical compound which can be attached to a metal ion by at least two bonds in such a way as to form a ring structure. It is used to sequester metal ions that might be undesirable in a particular environment.

"Commencement of construction" means any clearing of land, excavation, or other substantial action that would adversely affect the environment of a land disposal facility. The term does not mean disposal site exploration, necessary roads for disposal site exploration, borings to determine foundation conditions, or other preconstruction monitoring or testing to establish background information related to the suitability of the disposal site or the protection of environmental values.

"Commission" means the Nuclear Regulatory Commission or its duly authorized representatives.

"Director" means the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission.

"Disposal" means the isolation of radioactive wastes from the biosphere by emplacement in a land disposal facility.

"Engineered barrier" means a man-made structure or device that is intended to protect an intruder from inadvertent exposure to radiation from certain wastes.

"Disposal site" means that portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.

"Disposal unit" means a discrete portion of the disposal site into which waste is placed for disposal. For near-surface disposal the unit is usually a trench.

"Government agency" means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the government.

"Inadvertent intruder" means a person who might occupy the disposal site unknowingly after closure and engage in normal activities, such as agriculture, dwelling construction, and other pursuits in which the person might be exposed unknowingly to radiation from the waste.

"Indian Tribe" means an Indian tribe as defined in the Indian Self-Determination and Education Assistance Act (25 USC 450).

"Intruder barrier" means a sufficient depth of cover over the waste that inhibits contact with waste and helps to assure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in this part, or engineered structures that provide equivalent protection to the inadvertent intruder.

"Hydrogeologic unit" means any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of groundwater.

"Land disposal facility" means the land, buildings, and equipment which is intended to be used for the disposal of radioactive wastes into the subsurface of the land. For purposes of this chapter, a geologic repository as defined in Part 60 is not considered a land disposal facility.

"License" means a license issued under the regulations in Parts 30 through 35, 40, 50, 61, or 70 of this chapter, including licenses to operate a production or utilization facility pursuant to Part 50 of this chapter. "Licensee" means the holder of such a license.

"Monitoring" means observing and making measurements to provide data to evaluate the performance and characteristics of the disposal site.

"Near-surface disposal facility" means land disposal facility in which radioactive waste is disposed of in or within the upper 15-20 meters of the earth's surface.

"Person" means (1) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, government agency other than the Commission or the Department of Energy, (except that the Department of Energy is considered a person within the meaning of the regulations in this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244)), any State or any political subdivision of or any political entity within a State, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (2) any legal successor, representative, agent, or agency of the foregoing.

"Site closure and stabilization" means those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assure that the disposal site remain stable and will not need ongoing active maintenance.

"State" means any State, Territory, or possession of the United States, the Canal Zone, Puerto Rico, and the District of Columbia.

"Surveillance" means observation of the disposal site for purposes of visual detection of need for maintenance, custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.

"Tribal Governing Body" means a Tribal organization as defined in the Indian Self-Determination and Education Assistance Act (25 U.S.C. 450).

"Waste", for purposes of this part, means those low-level radioactive wastes containing source, special nuclear, or byproduct material that are acceptable for disposal in a land disposal facility. For the purposes of this definition, low-level waste has the same meaning as in the Low-Level Waste Policy Act, that is radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11e.(2) of the Atomic Energy Act.

§ 61.3 License required.

(a) No person may receive, possess, and dispose of radioactive waste containing source, special nuclear, or byproduct material at a land disposal facility unless authorized by a license issued by the Commission pursuant to this part.

(b) Each person shall file an application with the Commission and obtain a license as provided in this part before commencing construction of a land disposal facility. Failure to comply with this requirement may be grounds for denial of a license.

§ 61.4 Communications.

Except where otherwise specified, all communications and reports concerning the regulations in this part and applications filed under them should be addressed to the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications reports, and applications may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C. or 7915 Eastern Avenue, Silver Spring, Maryland.

§ 61.5 Interpretations.

Except as specifically authorized by the Commission, in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be considered binding upon the Commission.

§ 61.6 Exemptions.

The Commission may, upon application by an interested person, or upon its own initiative, grant any exemption from the requirements of the regulations in this part as it determines is authorized by law, will not endanger life or property or the common defense and security, and is otherwise in the public interest.

§ 61.7 Concepts.

(a) *The Disposal facility.* (1) Part 61 is intended to apply to *land disposal* of radioactive waste and not to other methods such as sea or extraterrestrial disposal. In its present form, Part 61 contains procedural requirements and performance objectives applicable to any method of land disposal. It contains specific technical requirements for *near-*

surface disposal of radioactive waste which involves disposal in the uppermost 15 to 20 meters of the earth. Technical requirements for alternative methods will be added in the future.

(2) Near-surface disposal of radioactive waste takes place at a *near-surface disposal facility*, which includes all of the land and buildings necessary to carry out the disposal. The *disposal site* is that portion of the facility which is used for disposal of waste and consists of *disposal units* and a *buffer zone*. A *disposal unit* is a discrete portion of the disposal site into which waste is placed for disposal. For near-surface disposal, the disposal unit is usually a trench. A *buffer zone* is a portion of the disposal site that is controlled by the licensee and that lies between the boundary of the disposal site and any disposal unit. It provides controlled space to establish *monitoring* locations which are intended to provide an early warning of radionuclide movement, and to take mitigative measures if needed.

(b) *Waste Classification and Near-Surface Disposal.* (1) Disposal of radioactive waste in near-surface disposal facilities has two primary safety objectives: *prevention of migration* of radionuclides, primarily through *groundwater*; and prevention of exposure to *inadvertent intruders*.

(2) A cornerstone of the system to control the migration of radionuclides offsite is *stability*—stability of the waste and the disposal site so that once emplaced and covered, the access of water to the waste can be eliminated or minimized. While stability is a necessary characteristic for waste that has a potential for migration, much radioactive waste does not contain sufficient amounts of radionuclides to be of concern from this standpoint; this waste, however, tends to be unstable, such as ordinary trash type wastes. If mixed with the higher activity waste, their deterioration could lead to failure of the system and permit water to penetrate the disposal unit and cause problems with the higher activity waste. Therefore, in order to avoid placing requirements for a stable waste form on relatively innocuous waste, these wastes have been classed as *Class A segregated* waste. Even though the Class A segregated waste is unstable, it decays to acceptable levels during the period when the site is occupied and active maintenance can control water infiltration. Those higher activity wastes that should be stable for proper disposal are classed as *Class B stable* waste. The Class A segregated waste will be disposed of in separate disposal units at the disposal site. For certain isotopes, a maximum disposal site inventory will be established based on the characteristics of the disposal site.

(3) It is possible but unlikely that persons might occupy the site in the future and engage in normal pursuits without knowing that they were receiving radiation exposure. These persons are referred to as *inadvertent intruders*. Protection of such intruders can involve two principal controls: *institutional control* over the site after operations by the site owner to assure that no such occupation or improper use of the site occurs; or, designating which waste would present an unacceptable risk to an intruder, and disposing of this waste in a manner that provides some form of *intruder barrier* that is intended to prevent contact with the waste. This regulation incorporates both types of protective controls.

(4) Institutional control is relied on for periods up to *100 years* to control access to the closed site. This permits the disposal of Class A segregated and Class B stable waste without special provisions for intrusion protection, since these classes of waste contain types and quantities of radioisotopes that will decay during the 100-year period to levels that do not pose a danger to public health and safety.

(5) Waste that will not decay to such levels within 100 years is designated as *Class C intruder* waste. This waste is disposed of at a greater depth than the other classes of waste so that subsequent surface activities by an intruder will not disturb the waste. Where site conditions prevent deeper disposal, *engineered barriers* such as concrete covers may be used. The assumed effective life of these intruder barriers is 500 years. A *maximum concentration* of radionuclides is specified for all wastes so that at the end of the 500 year period, remaining radioactivity is at a level that does not pose a danger to public health and safety. Waste with concentrations above these limits is generally unacceptable for near-surface disposal. Some provisions are made for exceptions on a case-by-case basis. Class C intruder waste must also be stable, since stability contributes to intruder protection by providing a recognizable and nondispersible waste form.

(c) *The Licensing Process.* (1) During the *preoperational phase*, the potential applicant goes through a process of *disposal site selection* by selecting a region of interest and examining a number of possible disposal sites and narrowing the choice to the *proposed* site. Through a detailed investigation of the *disposal site characteristics* the potential applicant obtains data on which to base an analysis of the disposal site's suitability. Along with these data and analyses, the applicant submits other more general information to the Commission in the form of an *application* for a license for land disposal. The Commission's review of the application is in accordance with established administrative procedures and may involve *participation* by affected *State governments* or *Indian tribes*. While the proposed disposal site must be owned by a State or the Federal government before the Commission will issue a license, it may be privately owned during the preoperational phase if suitable arrangements have been made with a State or the Federal government to take ownership in fee of the land before the license is issued.

(2) During the *operational phase*, the licensee carries out disposal activities in accordance with the requirements of this regulation and any conditions on the license. Periodically, the authority to conduct the above surface operations and receive waste will be subject to a *license renewal*, at which time the operating history will be reviewed and a decision made to permit or deny continued operation. When disposal operations are to cease, the licensee applies for an amendment to his license to permit *site closure*. After final review of the licensee's *site closure and stabilization plan*, the Commission may approve the final activities necessary to prepare the disposal site for the period of institutional control, without the need for ongoing *active maintenance* of the site.

(3) During the period when the site closure and stabilization activities are being carried out, the licensee is in a *disposal site closure* phase. Following that, for a period of at least 5 years, the licensee must remain at the disposal site for a period of *postclosure observation and maintenance* to assure that the disposal site is stable and ready for institutional control. At the end of this period, the licensee applies for a *license transfer* to the disposal site owner.

(4) After a finding of satisfactory disposal site closure, the Commission will transfer the license to the State or Federal agency that owns the disposal site. If the Department of Energy is the Federal agency the license will be terminated. Under the conditions of the transferred license, the owner will carry out a program of *monitoring* to assure continued satisfactory disposal site performance, physical *surveillance* to restrict access to the site and carry out minor *custodial activities*. At the end of

performed by the natural disposal site characteristics and design features in isolating and segregating the wastes. The analyses must clearly demonstrate that there is reasonable assurance that the exposures to humans from the migration of radioactivity will not exceed the limits set forth in § 61.41.

(b) Analyses of the protection of individuals from inadvertent intrusion must include demonstration that the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided.

(c) Analyses of the protection of individuals during operations must include assessments of expected exposures due to routine operations and likely accidents during handling, storage, and disposal of waste. The analyses must provide reasonable assurance that exposure will be controlled to meet the requirements of Part 20 of this chapter.

(d) Analyses of the long-term stability of the disposal site and the need for ongoing active maintenance after closure must be based upon analyses of active natural processes such as erosion, mass wasting, slope failure, settlement of wastes and backfill, infiltration through covers over disposal areas and adjacent soils and surface drainage of the disposal site. The analyses must provide reasonable assurance that there will not be a need for ongoing active maintenance of the disposal site following closure.

§ 61.14 Institutional information.

The institutional information must include:

(a) A certification by the Federal or State government agency which owns the disposal site that the agency is prepared to accept transfer of the license when the provisions of § 61.30 are met, and will assume responsibility for custodial care after site closure and post closure observation and maintenance.

(b) Where the proposed disposal site is on land not owned by the Federal or a State government, the applicant must submit evidence that arrangements have been made for assumption of ownership in fees by the Federal or a State government before the Commission issues a license.

§ 61.15 Financial information.

The financial information must be sufficient to demonstrate that the financial qualifications of the applicant are adequate to carry out the activities for which the license is sought and meet other financial assurance requirements as specified in Subpart E of this part.

§ 61.16 Other information.

Depending upon the nature of the wastes to be disposed of, and the design and proposed operation of the land disposal facility, additional information may be requested by the Commission including the following:

(a) Physical security measures, if appropriate. Any application to receive and possess special nuclear material in quantities subject to the requirements of Part 73 of this chapter shall demonstrate how the physical security requirements of Part 73 will be met. In determining whether receipt and possession will be subject to the requirements of Part 73, the applicant does not need to consider materials after disposal.

(b) Information concerning criticality, if appropriate.

(1) Any applicant to receive and possess special nuclear material in quantities that would be subject to the requirements of § 70.24, "Criticality accident requirements" of Part 70 of this chapter shall demonstrate how the requirements of this section will be met. In determining whether receipt and possession would be subject to the requirements of § 70.24, the applicant does not need to consider the quantity of special nuclear material that has been disposed.

(2) Any application to receive and possess special nuclear material shall describe procedures and provisions for criticality control which address both storage of special nuclear material prior to disposal and waste emplacement for disposal.

§ 61.20 Filing and distribution of application.

(a) An application for a license under this part, and any amendments thereto, shall be filed with the Director, must be signed by the applicant or the applicant's authorized representative, under oath and must consist of 1 signed original and 2 copies.

(b) Another 85 copies of the application and environmental report must be retained by the applicant for distribution in accordance with written instructions from the Director or designee.

(c) *Fees.* Application, amendment, and inspection fees applicable to a license covering the receipt and disposal of radioactive wastes in a land disposal facility are required by Part 170 of this chapter.

§ 61.21 Elimination of repetition.

In its application or environmental report, the applicant may incorporate by reference information contained in previous applications, statements, or reports filed with the Commission if these references are clear and specific.

§ 61.22 Updating of application and environmental report.

(a) The application and environmental report must be as complete as possible in the light of information that is available at the time of submittal.

(b) The applicant shall supplement its application or environmental report in a timely manner, as necessary, to permit the Commission to review, prior to issuance of a license, any changes in the activities proposed to be carried out or new information regarding the proposed activities.

§ 61.23 Standards for issuance of a license.

A license for the receipt, possession, and disposal of waste containing or contaminated with source, special nuclear, or byproduct material will be issued by the Commission upon finding that the issuance of the license will not be inimical to the common defense and security and will not constitute an unreasonable risk to the health and safety of the public, and:

(a) The applicant is qualified by reason of training and experience to carry out the disposal operations requested in a manner that protects health and minimizes danger to life or property.

(b) The applicant's proposed disposal site, disposal design, land disposal facility operations (including equipment, facilities, and procedures), disposal site closure, and postclosure institutional care are adequate to protect the public health and safety in that they provide reasonable assurance that the general population will be protected from releases of radioactivity as specified in the performance objective in § 61.41.

(c) The applicant's proposed disposal site, disposal site design, land disposal facility operations (including equipment, facilities, and procedures), disposal site closure, and postclosure institutional care are adequate to protect the public health and safety in that they provide reasonable assurance that doses to individual inadvertent intruders should not exceed the dose limits established in the performance objective in § 61.42.

(d) The applicant's proposed land disposal facility operations, including equipment, facilities, and procedures, are adequate to protect the public health and safety in that they provide reasonable assurance that the standards for radiation protection set out in Part 20 of this chapter will be met.

(e) The applicant's proposed disposal site, disposal site design, land disposal the prescribed period of institutional control, the license will be terminated by the Commission.

Subpart B—Licenses

§ 61.10 Content of application.

(a) An application to receive from others, possess, use and dispose of wastes containing or contaminated with source, byproduct or special nuclear material by land burial must consist of general information, specific technical information, institutional information, and financial information as set forth in §§ 61.11 through 61.16. An environmental report prepared in accordance with Part 51 of this chapter must accompany the application.

§ 61.11 General information.

The general information must include each of the following:

(a) Identity of the applicant including:

(1) The full name, address, telephone number and description of the business or occupation of the applicant;

(2) If the applicant is a partnership, the name, and address of each partner and the principal location where the partnership does business;

(3) If the applicant is a corporation or an unincorporated association, (i) the state where it is incorporated or organized and the principal location where it does business, and (ii) the names and addresses of its directors and principal officers; and

(4) If the applicant is acting as an agent or representative of another person in filing the application, all information required under this paragraph must be supplied with respect to the other person.

(b) Qualifications of the applicant:

(1) The organizational structure of the applicant, both offsite and onsite, including a description of lines of authority and assignments of responsibilities, whether in the form of administrative directives, contract provisions, or otherwise:

(2) The technical qualifications, including training and experience, of the applicant and members of the applicant's staff to engage in the proposed activities and minimum training and experience requirements for personnel filling key positions described in § 61.11(b)(1).

(3) A description of the applicant's personnel training program; and

(4) The plan to maintain an adequate complement of trained personnel to carry out waste receipt, handling, and disposal operations, in a safe manner.

(c) A description of:

(1) The location of the proposed disposal site:

(2) The general character of the proposed activities:

(3) The types and quantities of radioactive waste to be received, possessed, and disposed of:

(4) Plans for use of the land disposal facility for purposes other than disposal of radioactive wastes; and

(5) The proposed facilities and equipment.

(d) Proposed schedules for construction, receipt of waste, and first emplacement of waste at the proposed land disposal facility.

§ 61.12 Specific technical information.

The specific technical information must include the following information needed for demonstration that the performance objectives of Subpart C of this part and the applicable technical requirements of Subpart D of this part will be met:

(a) A description of the natural disposal site characteristics as determined by disposal site selection and characterization activities. The description must include geologic, technical hydrologic, meteorologic, climatologic, and biotic features of the disposal site and vicinity.

(b) A description of the design features of the land disposal facility and the disposal units. For near-surface disposal, the description must include those design features related to infiltration of water; integrity of covers for disposal units; structural stability of backfill, wastes, and covers; contact of wastes with standing water; disposal site drainage; disposal site closure and stabilization; elimination of long-term disposal site maintenance; inadvertent intrusion; occupational exposures; and disposal site monitoring.

(c) A description of the principal design criteria and their relationship to the performance objectives.

(d) A description of the design basis natural events or phenomena and their relationship to the principal design criteria.

(e) A description of codes and standards which the applicant has applied to the design and which will apply to construction of the land disposal facilities.

(f) A description of the construction and operation of the land disposal facility. The description must include the methods of construction; waste emplacement; the procedures for and areas of waste segregation; types of intruder barriers; onsite traffic and drainage systems; survey control program; methods and areas of waste storage; and methods to control surface water and groundwater access to the wastes.

(g) A description of the disposal site closure plan, including those design features which are intended to facilitate disposal site closure and to eliminate the need for ongoing active maintenance.

(h) An identification of the natural resources at the disposal site, the exploitation of which could result in inadvertent intrusion into the low-level wastes after removal of active institutional control.

(i) A description of the kind, amount, classification and specifications of the radioactive material proposed to be received, possessed, and disposed of at the land disposal facility.

(j) A description of the quality assurance program for the determination of natural disposal site characteristics and for quality assurance during the design, construction, and operation of the land disposal facility and the receipt, handling, and emplacement of waste. Audits and managerial controls must be included.

(k) A description of the radiation safety program for control and monitoring radioactive effluents and occupational radiation exposure to demonstrate compliance with the requirements of Part 20 of this chapter and to control contamination of personnel, vehicles, equipment, buildings, and the disposal site. Both routine operations and accidents must be addressed. The program description must include procedures, instrumentation, facilities, and equipment.

(l) A description of the environmental monitoring program to provide data to evaluate potential health and environmental impacts and the plan for taking corrective measures if migration of radionuclides is indicated.

(m) A description of the administrative procedures that the applicant will apply to control activities at the land disposal facility.

§ 61.13 Technical analyses.

The specific technical information must also include the following analyses needed to demonstrate that the performance objectives of Subpart C of this part will be met:

(a) Pathways analyzed in demonstrating protection of the general population from releases of radioactivity including air, soil, groundwater, surface water, plant uptake, and exhumation by burrowing animals. For near-surface disposal, the groundwater pathway will generally be the most significant in terms of releases of radioactivity. The migration analyses must clearly identify and differentiate between the roles facility operations, disposal site closure, and postclosure institutional care are adequate to protect the public health and safety in that they provide reasonable assurance of long-term stability of the disposed waste and the disposal site and should eliminate the need for ongoing active maintenance of the disposal site following closure.

(f) There is adequate demonstration that the applicable technical requirements of Subpart D of this part will be met.

(g) Institutional care is assured for the length of time found necessary to assure the findings in paragraphs (b)–(e) of this section and that the institutional care meets the requirements of §§ 61.59 and 61.60.

(h) The information on financial assurances meets the requirements of subpart E of this part.

(i) The applicant has demonstrated compliance with the requirements of Part 73 of this chapter, insofar as they are applicable to special nuclear material to be possessed under the license.

(j) The applicant has demonstrated compliance with the requirements of § 70.24 of Part 70 of this chapter, insofar as they are applicable to special nuclear material to be possessed under the license.

(k) Any additional information submitted as requested by the Commission pursuant to § 61.16 is adequate.

(l) The requirements of Part 51 of this chapter have been met.

§ 61.24 Conditions of licenses.

(a) A license issued under this part, or any right thereunder, may be transferred, assigned, or in any manner disposed of, either voluntarily, directly or indirectly, through transfer of control of the license to any person, only if the Commission finds, after securing full information, that the transfer is in accordance with the provisions of the Atomic Energy Act and gives its consent in writing in the form of a license amendment.

(b) The licensee shall submit written statements under oath upon request of the Commission, at any time before termination of the license, to enable the Commission to determine whether or not the license should be modified, suspended, or revoked.

(c) The license will be terminated only on the full implementation of the final closure plan as approved by the Commission, including postclosure observation and maintenance.

(d) The licensee shall be subject to the provisions of the Atomic Energy Act now or hereafter in effect, and to all rules, regulations, and orders of the Commission. The terms and conditions of the license are subject to amendment, revision, or modification, by reason of amendments to, or by reason of rules, regulations, and orders issued in accordance with the terms of the Atomic Energy Act.

(e) Any license may be revoked, suspended or modified in whole or in part for any material false statement in the application or any statement of fact required under Section 182 of the Act, or because of conditions revealed by any application or statement of fact or any report, record, or inspection or other means which would warrant the Commission to refuse to grant a license to the original application, or for failure to operate the facility in accordance with the terms of the license, or for any violation of, or failure to observe any of the terms and conditions of the Act, or any regulation, license or order of the Commission.

(f) Each person licensed by the Commission pursuant to the regulations in this part shall confine possession and use of materials to the locations and purposes authorized in the license.

(g) No radioactive waste may be disposed of until the Commission has inspected the land disposal facility and has found it to be in conformance with the description, design, and construction described in the application for a license.

(h) The Commission may incorporate in any license at the time of issuance, or thereafter, by appropriate rule, regulation or order, additional requirements and conditions with respect to the licensee's receipt, possession, and disposal of source, special nuclear or byproduct material as it deems appropriate or necessary in order to:

(1) Promote the common defense and security;

(2) Protect health or to minimize danger to life or property;

(3) Require such reports and the keeping of records, and to provide for such inspections of activities under the license that may be necessary or appropriate to effectuate the purposes of the Act and regulations thereunder.

(i) Any licensee who receives and possesses special nuclear material under this part in quantities that would be subject to the requirements of § 70.24 of Part 70 of this chapter shall comply with the requirements of that section. The licensee does not need to consider the quantity of materials which it has disposed.

§ 61.25 Changes.

(a) Except as provided for in specific license conditions, the licensee shall not make changes in the land disposal facility or procedures described in the license application. The license will include conditions restricting subsequent changes to the facility and the procedures authorized. These restrictions will fall into three categories of descending importance to public health and safety as follows: (1) those features and procedures which may not be changed without (i) 60 days prior notice to the Commission, (ii) 30 days notice of opportunity for a prior hearing, and (iii) prior Commission approval; (2) those features and procedures which may not be changed without (i) 60 days prior notice to the Commission, and (ii) prior Commission approval; and (3) those features and procedures which may not be changed without 60 days prior notice to the Commission. Features and procedures falling in paragraph (a)(3) of this section may not be changed without prior Commission approval if the Commission, after having received the required notice, so orders.

(b) Amendments authorizing license renewal, site closure, license transfer, or license termination shall be included in paragraph (a)(1) of this section.

§ 61.26 Amendment of license.

(a) An application for amendment of a license must be filed in accordance with § 61.20 and shall fully describe the changes desired.

(b) In determining whether an amendment to a license will be approved, the Commission will apply the criteria set forth in § 61.23.

§ 61.27 Application for renewal or closure.

(a) Any expiration date on a license applies only to the above ground activities and to the authority to dispose of waste. Failure to renew the license in no way relieves the licensee of responsibility for carrying out site closure, postclosure observation and transfer of the license to the site owner. An application for renewal or an application for closure under § 61.28 must be filed at least 30 days prior to license expiration.

(b) Applications for renewal of a license must be filed in accordance with §§ 61.10 through 61.16 and 61.20. Applications for closure must be filed in accordance with §§ 61.20 and 61.28. Information contained in previous applications, statements or reports filed with the Commission under the license may be incorporated by reference if the references are clear and specific.

(c) In any case in which a licensee has timely filed an application for renewal a license, the license for continued ceipt and disposal of licensed materials does not expire until the Commission has taken final action on the application for renewal.

(d) In determining whether a license will be renewed, the Commission will apply the criteria set forth in § 61.23.

§ 61.28 Content of application for closure.

(a) Prior to final closure of the disposal site, or as otherwise directed by the Commission, the applicant shall submit an application to amend the license for closure. This closure application must include a final revision and specific details of the disposal site closure plan included as part of the license application submitted under § 61.12(g) that includes each of the following:

(1) Any additional geologic, hydrologic, or other disposal site data pertinent to the long-term containment of emplaced radioactive wastes obtained during the operational period.

(2) The results of tests, experiments, or any other analyses relating to backfill of excavated areas, closure and sealing, waste migration and interaction with emplacement media, or any other tests, periments, or analysis pertinent to the g-term containment of emplaced aste within the disposal site.

(3) Any proposed revision of plans for:

(i) Decontamination and/or dismantlement of surface facilities;

(ii) Backfilling of excavated areas; or

(iii) Stabilization of the disposal site for post-closure care.

(4) Any significant new information regarding the environmental impact of closure activities and long-term performance of the disposal site.

(b) Upon review and consideration of an application to amend the license for closure submitted in accordance with paragraph (a) of this section, the Commission shall issue an amendment authorizing closure if there is reasonable assurance that the long-term performance objectives of Subpart C of this part will be met.

§ 61.29 Post-closure observation and maintenance.

Following completion of closure authorized in § 61.28, the licensee shall observe, monitor, and carry out necessary maintenance and repairs at the disposal site until the site closure is complete and the license is transferred the Commission in accordance with ..30. Responsibility for the disposal ..e must be maintained by the licensee for a minimum of 5 years.

§ 61.30 Transfer of license.

(a) Following closure and the period of post-closure observation and maintenance, the licensee may apply for an amendment to transfer the license to the disposal site owner. The license shall be transferred when the Commission finds:

(1) That the closure of the disposal site has been made in conformance with the licensee's disposal site closure plan, as amended and approved as part of the license;

(2) That reasonable assurance has been provided by the licensee that the performance objectives of Subpart C of this part are met;

(3) That any funds and necessary records for care will be transferred to the disposal site owner;

(4) That the post-closure monitoring program is operational for implementation by the disposal site owner; and

(5) That the Federal or State government agency which will assume responsibility for custodial care of the disposal site is prepared to assume responsibility and assure that the institutional requirements found necessary under § 61.23(g) will be met.

§ 61.31 Termination of license.

(a) Following any period of custodial care needed to meet the requirements found necessary under § 61.23, the licensee may apply for an amendment to terminate the license.

(b) This application must be filed, and will be reviewed, in accordance with the provision of § 61.20 and of this section.

(c) A license is terminated only when the Commission finds:

(1) That the institutional care requirements found necessary under § 61.23(g) have been met; and

(2) That any additional requirements resulting from new information developed during the custodial period have been met.

Subpart C—Performance Objectives

§ 61.40 General requirement.

Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in §§ 61.41 through 61.44.

§ 61.41 Protection of the general population from releases of radioactivity.

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. In addition, concentrations of ratioactive material in groundwater must not exceed the maximum contaminant levels established in the National Primary Drinking Water Standards (40 CFR Part 141) at the nearest public drinking water supply (a limit of 10 pCi/1 above background must be used for uranium and thorium).

§ 61.42 Protection of individuals from inadvertent intrusion.

Design operation and closure of the land disposal facility must not result in conditions where any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed, could receive a dose to the whole body in excess of 500 millirem per year.

§ 61.43 Protection of individuals during operations.

Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter.

§ 61.44 Stability of the disposal site after closure.

The disposal facility must be designed, used, operated, and closed to achieve long-term stability of the disposed waste and the disposal site and to eliminate the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required.

Subpart D—Technical Requirements for Land Disposal Facilities

§ 61.50 Disposal site suitability requirements for land disposal.

(a) Disposal site suitability for near-surface disposal.

(1) The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal site. The primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that assure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits.

(2) The disposal site shall be capable of being characterized, modeled, analyzed and monitored.

(3) Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

(4) Areas must be avoided having economically significant natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part.

(5) The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year flood plain, coastal high-hazard area or wetland.

(6) Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or innundate waste disposal units.

(7) The disposal site must provide sufficient depth to the water table that ground water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider exceptions to this requirement if it can be conclusively shown that disposal site characteristics will result in diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met.

(8) Any groundwater discharge to the surface within the disposal site must not originate within the hydrogeologic unit used for disposal.

(9) Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C, of this part or may preclude defensible modeling and prediction of long-term impacts.

(10) Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C, of this part or may preclude defensible modeling and prediction of long-term impacts.

(11) The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program.

(b) Disposal site suitability requirements for land disposal other than near-surface (reserved).

§ 61.51 Disposal site design for land disposal.

(a) Disposal site design for near-surface disposal.

(1) Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance.

(2) The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met.

(3) The disposal site must be designed to complement and improve the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met.

(4) Covers must be designed to prevent water infiltration, to direct precolating or surface water away from the buried waste, and to resist degradation by surface geologic processes and biotic activity.

(5) Surface features must direct surface water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future.

(6) The disposal site must be designed to eliminate the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal.

(7) The disposal site shall be used exclusively for the disposal of radioactive wastes.

(b) Disposal site design for other than near-surface disposal (reserved).

§ 61.52 Land disposal facility operation and disposal site closure.

(a) Near-surface disposal facility operation and disposal site closure.

(1) Wastes designated as Class A segregated, pursuant to § 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from other units so that there is no interaction between them.

(2) Wastes designated as Class B stable, pursuant to § 61.55, shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (10) of this section.

(3) Wastes designated as Class C intruder, pursuant to § 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the surface of the cover or must be disposed of with natural or engineered barriers that are designed to protect against an inadvertent intrusion for at least 500 years.

(4) Wastes must be emplaced in an orderly manner that maintains the package integrity during emplacement and disposal.

(5) Void spaces between waste packages must be filled with earth or other material to reduce future subsidence within the fill.

(6) Waste must be placed and covered in a manner that limits the gamma radiation at the surface of the cover to levels that are within a few percent above the natural background levels of the site.

(7) The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files.

(8) A buffer zone of land must be maintained between any buried waste and the disposal site boundary. The buffer zone shall extend at least 100 feet outward from the outermost waste disposal units.

(9) Adequate closure and stabilization measures must be carried out as each disposal unit (e.g., each trench) is filled and covered.

(10) Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures.

(b) Facility operations and disposal site closure for land disposal facilities other than near-surface (reserved).

§ 61.53 Environmental monitoring.

(a) At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period.

(b) During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and enable the evaluation of long-term effects and the need for mitigative measures.

(c) After the disposal site is closed, the licensee responsible for post-operational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of migration of radionuclides from the disposal site.

(d) The licensee must have plans for taking corrective measures if migration of radionuclides would incidate that the performance objectives of Subpart C would not be met.

§ 61.54 Alternative requirements for design and operations.

The Commission may, upon request or on its own initiative, authorize provisions other than those set forth in §§ 61.51 through 61.53 for the segregation and disposal of waste and for the design and operation of a land disposal facility on a specific basis, if it finds reasonable assurance of compliance with the performance objectives of Subpart C of this part.

§ 61.55 Waste classification.

Radioactive wastes are defined to fall within one of the following categories:

(a) *Class A segregated waste* is waste that is segregated at the disposal site and disposed of with only minimum requirements on waste form and characteristics and has the following properties:

(1) the radioisotope concentration does not exceed the values shown in Column 1, Table I, of this section; and

(2) the physical form and characteristics must meet the minimum requirements set forth in § 61.56(a).

(b) *Class B stable waste* is waste that must meet more rigorous requirements on waste form to assure stability after disposal, and has the following properties:

(1) the radioisotope concentration exceeds the concentrations shown in Column 1; and,

Table 1

Isotope	Column 1[1]	Column 2[2]	Column 3[3]
Any with half-life less than 5 years	700	70 000	Theoretical maximum specific activity
H-3	40	10^4	Theoretical maximum specific activity[4]
C-14	0.8	0.8	0.8[4]
Ni-59	2.2	2.2	2.2
Co-60	700	70,000	Theoretical maximum specific activity
Ni-63	3.5	70	70
Nb-94	0.002	0.002	0.002
Sr-90	0.04	150	700
Tc-99	0.3	0.3	0.3[4]
I-129	0.008	0.008	0.008[4]
Cs-135	84	84	84
Cs-137	1.0	44	4600
Enriched Uranium	0.04	0.04	0.04
Natural or Depleted uranium	0.05	0.05	0.05
Alpha-emitting transuranic isotopes			10 nCi/g
Pu-241			350 n Ci/g

[1] Maximum concentration for Class A segregated waste. Above this, it is Class B stable waste μCi/cm³

[2] Concentrations above which some wastes become Class C intruder waste μCi/cm³

[3] Maximum concentration for any waste class μCi/cm³

[4] Near-surface disposal facilities will be limited to a specified quantity for the disposal site. This quantity will be determined at the time the license is issued and will be governed largely by the characteristics of the site. Therefore, the total activity of these isotopes in each package of waste must be shown on the shipping manifest (see § 20.311 of this chapter).

For isotopes contained in metals, metal alloys, or permanently fixed on metal as contamination, the values above may be increased by a factor of ten, except natural or depleted uranium which can be the natural specific activity.

For isotopes not listed above, use the values for Sr-90 for beta emitting isotopes with little or no gamma radiation; the values for Cs-137 for beta emitting isotopes with significant gamma radiation; and the values for U-235 for alpha emitting isotopes other than radium.

Wastes containing chelating agents in concentrations greater than 0.1% are not permitted except as specifically approved by the Commission.

For mixtures of the above isotopes, the sum of ratios of an isotope concentration in waste to the concentration in the above table shall not exceed one for any waste class.

Concentrations may be averaged over volume of the package. For a 55 gallon drum multiply the concentration limits by 200,000 to determine allowable total activity.

Until establishment and adoption of other values or criteria, the values in this table (or greater concentrations as may be approved by the Commission in particular cases) shall be used in categorizing waste for near-surface disposal.

(2) The physical form and characteristics of the waste must meet the *minimum* and *stability* requirements set forth in § 61.56.

(c) *Class C intruder waste* is waste that not only must meet more rigorous requirements on waste form to assure stability but also requires special measures at the disposal facility to protect against inadvertent intrusion. This class has the following properties:

(1) The radioisotope concentrations exceed those shown in Column 2; and

(2) The physical form and characteristics meet the *minimum* and *stability* requirements set forth in § 61.56 of this part.

(d) Waste that has a radioisotope concentration that exceeds the values shown in Column 3, Table I of this section, is not generally acceptable for near-surface disposal and shall not be disposed of without specific Commission approval pursuant to § 61.58 of this part.

§ 61.56 Waste characteristics.

(a) The following requirements are *minimum* requirements for all classes of waste and are intended to facilitate handling at the disposal site and provide protection of health and safety.

(1) The waste must be packaged and the waste form and packaging must meet all applicable transportation requirements of the Commission set forth in 10 CFR Part 71 and of the Department of Transportation set forth in 49 CFR Parts 171–179, as applicable.

(2) Wastes must not be packaged for disposal in cardboard or fiberboard boxes.

(3) Waste containing liquids must be packaged in sufficient absorbent material to absorb twice the volume of the liquid.

(4) Waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.

(5) Waste must not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste.

(6) Wastes must not be pyrophoric. Pyrophoric materials contained in wastes shall be treated, prepared, and packaged to be nonflammable.

(7) Wastes in a gaseous form must be packaged at a pressure that does not exceed one atmosphere at 20° C. Total activity must not exceed 100 curies per container.

(8) Wastes containing biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard.

(b) The requirements in this section are intended to provide *stability* of the waste for at least 150 years. Stability is intended to assure that the waste does not degrade and promote slumping, collapse, or other failure of the disposal unit and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste.

(1) Waste must have structural stability. A structurally stable waste form will maintain its physical dimensions within 5% and its form, under the expected disposal conditions of compressive load of 50 psi, and factors such as the presence of moisture, and microbial activity, and internal factors such as as radiation effects and chemical changes. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a disposal container or structure that provides stability after disposal.

(2) Notwithstanding the provisions in § 61.56(a)(3), liquid wastes, or wastes containing liquid, must be converted into a form that contains as little free standing noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume of the waste.

(3) Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.

§ 61.57 Labeling.

Each package of waste must be clearly labeled to identify whether it is *Class A segregated, Class B stable*, or *Class C intruder*, in accordance with § 61.55.

§ 61.58 Alternative requirements for waste classification and characteristics.

The Commission may, upon request or on its own initiative, authorize other provisions for the classification and characteristics of waste on a specific basis, if, after evaluation, of the specific characteristics of the waste, disposal site, and method of disposal, it finds reasonable assurance of compliance with the performance objectives in Subpart C of this part.

§ 61.59 Institutional requirements.

(a) *Land ownership.* Disposal of radioactive waste received from other persons may be permitted only on land owned in fee by the Federal or a State government.

(b) *Institutional control.* The land owner or custodial agency shall carry out an active institutional control program to physically control access to the disposal site following transfer of control of the disposal site from the disposal site operator. The active control program must also include, but not be limited to, carrying out an environmental monitoring program at the disposal site, periodic suveillance, minor custodial care, and other requirements as determined by the Commission and administration of funds to cover the costs for these activities. The period of active controls will be determined by the Commission, but active controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the owner.

Subpart E—Financial Assurances

§ 61.61 Applicant qualification and assurances.

Each applicant shall show that it either possesses the necessary funds or has reasonable assurance of obtaining the necessary funds, or by a combination of the two, to cover the estimated costs of conducting all licensed activities over the planned operating life of the project, including costs of construction and disposal.

§ 61.62 Funding for disposal site closure and stabilization.

(a) The applicant shall provide assurances prior to the commencement of operations that sufficient funds will be available to carry out disposal site closure and stabilization, including: (1) decontamination or dismantlement of land disposal facility structures; and (2) closure and stabilization of the disposal site so that following transfer of the disposal site to the owner, the need for ongoing active maintenance is eliminated and only minor custodial care, surveillance, and monitoring are required. These assurances shall be based on Commission approved cost estimates reflecting the Commission approved plan for disposal site closure and stabilization. The applicant's cost estimates must take into account total capital costs that would be incurred if an independent contractor were hired to perform the closure and stabilization work.

(b) In order to avoid unnecessary duplication and expense, the Commission will accept financial sureties that have been consolidated with earmarked financial or surety arrangements established to meet requirements of other Federal or State agencies and/or local governing bodies for such decontamination, closure and stabilization. The Commission will accept this arrangement only if they are considered adequate to satisfy these requirements and that the portion of the surety which covers the closure of the disposal site is clearly identified and committed for use in accomplishing these activities.

(c) The licensee's surety mechanism will be reviewed by the Commission annually to assure sufficient funds for completion of the closure plan if the work has to be performed by an independent contractor.

(d) The amount of surety liability should change in accordance with the predicted cost of future closure and stabilization. Factors affecting closure and stabilization cost estimates include: inflation; increases in the amount of disturbed land; changes in engineering plans; closure and stabilization that has already been accomplished and any other conditions affecting costs. This will yield a surety that is at least sufficient at all times to cover the costs of closure of the disposal units that are expected to be used before the next license renewal.

(e) The term of the surety mechanism must be open ended unless it can be demonstrated that another arrangement would provide an equivalent level of assurance. This assurance could be provided with a surety mechanism which is written for a specified period of time (e.g., five years) yet which must be automatically renewed unless the party who issues the surety notifies the beneficiary (the Commission) and the principal (the licensee) not less than 90 days prior to the renewal date of its intention not to renew. In such a situation the licensee must submit a replacement surety within 30 days after notification of cancellation. If the licensee fails to provide a replacement surety acceptable to the Commission, the Commission will collect on the original surety.

(f) Proof of forfeiture must not be necessary to collect the surety so that in the event that the licensee could not provide an acceptable replacement surety within the required time, the surety shall be automatically collected prior to its expiration. The conditions described above would have to be clearly stated on any surety instrument which is not open-ended, and must be agreed to by all parties. Liability under the surety mechanism must remain in effect until the closure and stabilization program has been completed and approved by the Commission and the license has been transferred to the site owner.

(g) Financial surety arrangements generally acceptable to the Commission include: surety bonds, cash deposits, certificates of deposit, deposits of government securities, escrow accounts, irrevocable letters or lines of credit, trust funds, and combinations of the above or such types of arrangements as may be approved by the Commission. However, self-insurance, or any arrangement which essentially constitutes pledging the assets of the licensee, will not satisfy the surety requirement for private sector applicants since this provides no additional assurance other than that which already exists through license requirements.

§ 61.63 Financial assurances for institutional control.

(a) Prior to the issuance of the license, the applicant shall provide for Commission review and approval a copy of a binding arrangement, such as a lease, between the applicant and the disposal site owner that ensures that sufficient funds will be available to cover the costs of monitoring, and any required maintenance during the institutional control period. The binding arrangement will be reviewed periodically by the Commission to ensure that changes in inflation, technology and disposal facility operations are reflected in the arrangements.

(b) Subsequent changes to the binding arrangement specified in paragraph (a) of this section relevant to institutional control shall be submitted to the Commission for approval.

Subpart F—Participation by State Governments and Indian Tribes

§ 61.70 Scope.

This subpart describes mechanisms through which the Commission will implement a formal request from a State or Tribal government to participate in the review of a license application for a land disposal facility. Nothing in this subpart may be construed to bar the State or tribal-governing body from participating in subsequent Commission proceedings concerning the license application as provided under Federal law and regulations.

§ 61.71 State and tribal government consultation.

Upon request of a State or tribal government body, the Director may make available Commission staff to discuss with representatives of the State or tribal governing body information submitted by the applicant, applicable Commission regulations, licensing procedures, potential schedules, and the type and scope of State activities in the license review permitted by law. In addition, staff will be made available to consult and cooperate with the State or tribal governing body in developing proposals for participation in the license review.

§ 61.72 Filing of proposals for State and tribal participation.

(a) Following publication in the Federal Register of the notice of docketing, but no later than 120 days following docketing of an application submitted under § 61.20, a State or tribal-governing body potentially affected a near-surface disposal facility at the proposed site may submit to the Director a proposal for participation in the review of the license application. A State or tribal governing body may also submit to the Director a proposal for participation in the review of any subsequent application for license renewal or amendment.

(b) Proposals for participation in the licensing process must be made in writing and must be signed by the Governor of the State or the official otherwise provided for by State or Tribal law.

(c) At a minimum, proposals must contain each of the following items of information:

(1) A general description of how the State or tribe wishes to participate in the licensing process specifically identifying those issues it wishes to review.

(2) A description of material and information which the State or tribe plans to submit to the Commission for consideration in the licensing process. A tentative schedule referencing steps in the review and calendar dates for planned submittals should be included.

(3) A description of any work that the State or tribe proposes to perform for the Commission in support of the licensing process.

(4) A description of state or tribal plans to facilitate local government and citizen participation.

(5) A preliminary estimate of the types and extent of impact which the State expects, should be a disposal facility be located as proposed.

(6) If desired, any requests for educational or information services (seminars, public meetings) or other actions from the Commission such as establishment of additional Public Document Rooms or exchange of State personnel under the Intergovernmental Personnel Act.

§ 61.73 Commission approval of proposals.

(a) Upon receipt of a proposal submitted in accordance with § 61.72, the Director will arrange for a meeting between the representatives of the State or tribal governing body and the Commission staff to discuss the proposal and to ensure full and effective participation by the State or tribe in the Commission's license review.

(b) If requested by a State or tribal governing body, the Director may approve all or any part of a proposal if the Director determines that:

(1) The proposed activities are within the scope of Commission statutory responsibility and the type and magnitude of impacts which the State or tribe may bear are sufficient to justify their participation; and

(2) The proposed activities will contribute productively to the licensing review.

(c) The decision of the Director will be transmitted in writing to the Governor or the designated official of the tribal governing body.

(d) Upon the written request of the Governor or the tribal official, any determination of the Director under this section may be reviewed by the Commission.

Subpart G—Records, Reports, Tests, and Inspections

§ 61.80 Maintenance of records, reports, and transfers.

(a) Each licensee shall maintain any records and make any reports in connection with the licensed activities as may be required by the conditions of the license or by the rules, regulations, and orders of the Commission.

(b) Records which are required by the regulations in this Part or by license conditions must be maintained for a period specified by the appropriate regulations in this chapter or by license condition. If a retention period is not otherwise specified, these records must be maintained and transferred as a condition of license termination unless the Commission otherwise authorizes their dispostion.

(c) Records which must be maintained pursuant to this Part may be the original or a reproduced copy of microfilm if this reproduced copy or microfilm is capable of producing a clear and legible copy.

(d) If there is a conflict between the Commission's regulations in this part, license condition, or other written Commission approval or authorization pertaining to the retention period for the same type of record, the longest retention period specified takes precedence.

(e) Notwithstanding paragraphs (a) through (d) of this section, copies of records of the location and the quantity of radioactive wastes contained in the disposal site must be transferred upon license termination to the chief executive of the nearest municipality, the chief executive of the county in which the facility is located, the county zoning board or land development and planning agency, the state governor and other State, local and Federal governmental agencies as designated by the Commission at the time of license termination.

(f) Each licensee shall comply with the reporting requirements of § 30.55 of this chapter, § 40.64 of this chapter, and § 70.53 and § 70.54 of Part 70 of this chapter if the quantities or activities of materials received or transferred exceed the limits of these sections. Inventory reports are not required for materials after disposal.

(g) Each licensee authorized to dispose of radioactive waste received from other persons, shall, upon each issuance of its annual financial report, if any, including any certified financial statements, file a copy thereof with the Commission in order to update the information base for determining financial qualifications.

(h)(1) Each licensee authorized to dispose of waste materials received from other persons, pursuant to this part, shall submit annual reports to the appropriate Commission regional office shown in Appendix D of Part 20 of this chapter, with copies to the Director of the Office of Inspection and Enforcement and the Director of the Division of Waste Management, USNRC, Washington, D.C. 20555. Reports shall be submitted by the end of the first calendar quarter of each year for the preceding year; (2) the reports shall include (i) specification of the quantity of each of the principal radionuclides released to unrestricted areas in liquid and in airborne effluents during the preceding year, (ii) the results of the environmental monitoring program, (iii) a summary of licensee disposal site maintenance activities, (iv) summary of activities and quantities of radionuclides disposed of, (v) any instances in which observed site characteristics were different from those described in the application for a license, and (vi) any other information the Commission may require. If the quantities of radioactive materials released during the reporting period, monitoring results, or maintenance performed are significantly different from those expected in the materials previously reviewed as part of the licensing action, the report must cover this specifically.

(i) Each licensee shall report in accordance with the requirements of § 70.52 of this chapter.

(j) Any transfer of byproduct, source, and special nuclear materials by the licensee is subject to the requirements in § 30.41 of Part 30 of this chapter, § 40.51 of Part 40 of this chapter, and § 70.42 of Part 70 of this chapter. Byproduct, source and special nuclear material means materials as defined in these Parts, respectively.

§ 61.81 Tests at land disposal facilities.

(a) Each licensee shall perform, or permit the Commission to perform, any tests as the Commission deems appropriate or necessary for the administration of the regulations in this Part, including tests of:

(1) Radioactive wastes and facilities used for the receipt, storage, treatment, handling and disposal of radioactive wastes;

(2) Radiation detection and monitoring instruments; and

(3) Other equipment and devices used in connection with the receipt, possession, handling, treatment, storage, or disposal of radioactive waste.

§ 61.82 Commission inspections of land disposal facilities.

(a) Each licensee shall afford to the Commission at all reasonable times opportunity to inspect radioactive waste and the premises, equipment, operations, and facilities in which radioactive wastes are received, possessed, handled, treated, stored, or disposed.

(b) Each licensee shall make available to the Commission for inspection, upon reasonable notice, records kept by it pursuant to the regulations in this chapter. Authorized repesentatives of the Commission may copy, for the Commission's use, any record required to be kept pursuant to this part.

§ 61.83 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule.

The following amendments are also made to existing parts of the regulations in this chapter.

PART 2—RULES OF PRACTICE

2. In § 2.101, paragraph (a)(2), (b), and (d) are revised to read as follows:

§ 2.101 Filing of application.

(a) * * *

(2) Each application for a license for a facility will be assigned a docket number. However, to allow a determination as to whether an application for a construction permit or operating license for a production or utilization facility is complete and acceptable for docketing, it will be initially treated as a tendered application after it is received and a copy of the tendered application will be available for public inspection in the Commission's Public Document Room, 1717 H Street, NW., Washington, D.C. Generally, that determination will be made within a period of thirty (30) days.

* * * * *

(b) Each application for a license to receive radioactive waste from other persons for disposal under Part 61 of this chapter and the accompanying environmental report shall be processed in accordance with the provisions of this paragraph.

(1) To allow a determination as to whether the application or environmental report is complete and acceptable for docketing, it will be initially treated as a tendered document, and a copy will be available for public inspection in the Commission's Public Document Room, 1717 H Street, NW., Washington, D.C. One original and two copies shall be filed to enable this determination to be made.

(i) Upon receipt of a tendered application, the Commission will publish in the **Federal Register** notice of the filed application and will notify the governors, legislatures and other appropriate State, county, and muncipal officials and tribal governing bodies of the States and areas containing or potentially affected by the activities at the proposed site and the alternative sites. The Commission will inform these officials that the Commission staff will be available for consultation pursuant to § 61.71 of this chapter. The **Federal Register** notice will note the opportunity for interested persons to submit views and comments on the tendered application for consideration by the Commission and applicant.

(ii) The Commission will also post a public notice in a newspaper or newspapers of general circulation in the affected States and areas summarizing information contained in the applicant's tendered application and noting the opportunity to submit views and comments.

(iii) When the Director of Nuclear Material Safety and Safeguards determines that the tendered document is complete and acceptable for docketing, a docket number will be assigned and the applicant will be notified of the determination. If it is determined that all or any part of the tendered document is incomplete and therefore not acceptable for processing, the applicant will be informed of this determination and the aspects in which the document is deficient.

(2) With respect to any tendered document that is acceptable for

docketing, the applicant will be requested to (i) submit to the Director of Nuclear Material Safety and Safeguards such additional copies as the regulations in Parts 61 and 51 of this chapter require, (ii) serve a copy on the chief executive of the municipality in which the waste is to be disposed of or, if the waste is not to be disposed of within a municipality, serve a copy on the chief executive of the county in which the waste is to be disposed of (iii) make direct distribution of additional copies to Federal, State, Indian Tribe, and local officials in accordance with the requirements of this chapter and written instructions from the Director of Nuclear Material Safety and Safeguards and (iv) serve a notice of availability of the application and environmental report on the chief executives or governing bodies of the municipalities or counties which have been identified in the application and environmental report as the location of all or part of the alternative sites if copies are not distributed under paragraph (b)(2)(iii) of this section to the executives or bodies. All distributed copies shall be completely assembled documents identified by docket number. Subsequently distributed amendments, however, may include revised pages to previous submittals and, in such cases, the recipients will be responsible for inserting the revised pages. In complying with the requirements of paragraph (b) of this section the applicant shall not make public distribution of those parts of the application subject to § 2.790(d).

(3) The tendered document will be formally docketed upon receipt by the Director of Nuclear Material Safety and Safeguards of the required additional copies. Distribution of the additional copies shall be deemed to be complete as of the time the copies are deposited in the mail or with a carrier prepaid for delivery to the designated addressees. The date of docketing shall be the date when the required copies are received by the Director of Nuclear Material Safety and Safeguards. Within ten (10) days after docketing, the applicant shall submit to the Director of Nuclear Material Safety and Safeguards a written statement that distribution of the additional copies to Federal, State, Indian Tribe, and local officials has been completed in accordance with requirements of this section and written instructions furnished to the applicant by the Director of Nuclear Material Safety and Safeguards.

(4) Amendments to the application and environmental report shall be filed and distributed and a written statement shall be furnished to the Director of Nuclear Material Safety and Safeguards in the same manner as for the initial application and environmental report.

(5) The Director of Nuclear Material Safety and Safeguards will cause to be published in the **Federal Register** a notice of docketing which identifies the State and location of the proposed waste disposal facility and will give notice of docketing to the governor of that State and other officials listed in paragraph (b)(3) of this section and, in a reasonable period thereafter, publish in the **Federal Register** a notice pursuant to § 2.105 offering opportunity for a hearing to the applicant and other affected persons.

* * * * *

(d) The Director of Nuclear Reactor Regulation or Director of Nuclear Material Safety and Safeguards, as appropriate, will give notice of the docketing of the public health and safety, common defense and security, and environmental parts of an application for a license for a facility to the Governor or other appropriate official of the State in which the facility is to be located or the activity is to be conducted and will cause to be published in the **Federal Register** a notice of docketing of the application which states the purpose of the application and specifies the location at which the proposed activity would be conducted.

* * * * *

3. Section 2.103(a) is revised to read as follows:

§ 2.103 Action on applications for byproduct, source, special nuclear material, and operator licenses.

(a) If the Director of Nuclear Reactor Regulation or the Director of Nuclear Material Safety and Safeguards, as appropriate, finds that an application for a byproduct, source, special nuclear material, or operator license complies with the requirements of the Act, the Energy Reorganization Act, and this chapter, he will issue a license. If the license is for a facility or if it is to receive and possess high-level radioactive waste at a geologic repository operations area pursuant to Part 60 of this chapter, the Director of Nuclear Reactor Regulation or the Director of Nuclear Material Safety and Safeguards, as appropriate, will inform the State, Indian Tribe, and local officials specified in § 2.104(e) of the issuance of the license.

* * * * *

4. Section 2.104(e) is revised to read as follows:

§ 2.104 Notice of hearing.

* * * * *

(e) The Secretary will give timely notice of the hearing to all parties and to other persons, if any, entitled by law to notice. The Secretary will transmit a notice of hearing on an application for a facility license or for a license for receipt of waste radioactive material from other persons for the purpose of disposal under Part 61 of this chapter or for a license to receive and possess high-level radioactive waste at a geologic repository operations area pursuant to Part 60 of this chapter to the governor or other appropriate official of the State and to the chief executive of the municipality in which the facility is to be located or the activity is to be conducted or, if the facility is not to be located or the activity conducted within a municipality, to the chief executive of the county (or to the Tribal organization, if it is to be so located or conducted within an Indian reservation).

5. Section 2.105(a)(2) is revised to read as follows:

§ 2.105 Notice of proposed action.

(a) * * *

(2) A license for receipt of waste radioactive material from other persons for disposal by the waste disposal licensee under Part 61 of this chapter.

* * * * *

6. Section 2.106 is amended by adding a new paragraph (d) to read as follows:

§ 2.106 Notice of issuance.

* * * * *

(d) The Director of Nuclear Material Safety and Safeguards will also cause to be published in the **Federal Register** notice of, and will inform the State and local officials or tribal governing body specified in § 2.104(e) of any licensing action with respect to a license to receive radioactive waste from other persons for disposal under Part 61 of this chapter or the amendment of such a license for which a notice of proposed action has been previously published.

7. Section 2.764 is amended by adding a new paragraph (e), and by revising paragraphs (a) and (b) to read:

§ 2.764 Immediate effectiveness of initial decision directing issuance or amendment of construction permit or operating license.[1]

(a) Except as provided in paragraphs (c), (d), and (e) of this section, an initial decision directing the issuance or amendment of a construction permit, a construction authorization, or an operating license shall be effective immediately upon issuance unless the presiding officer finds that good cause has been shown by a party why the initial decision should not become immediately effective, subject to the review thereof and further decision by the Commission upon exceptions filed by any party pursuant to § 2.762 or upon its own motion.

(b) Except as provided in paragraphs (c), (d), and (e) of this section, the Director of Nuclear Reactor Regulation or Director of Nuclear Material Safety and Safeguards, as appropriate, notwithstanding the filing of exceptions, shall issue a construction permit, a construction authorization, or an operating license, or amendments thereto, authorized by an initial decision, within ten (10) days from the date of issuance of the decision.

* * * * *

(e) An initial decision directing the issuance of a license under Part 61 of this chapter (relating to land disposal of radioactive waste) or any amendment to such a license authorizing actions which may significantly affect the health and safety of the public, shall become effective only upon order of the Commission. The Director of Nuclear Material Safety and Safeguards shall not issue a license under Part 61 of this chapter, or any amendment to such a license which may significantly affect the health and safety of the public, until expressly authorized to do so by the Commission.

PART 19—NOTICES, INSTRUCTIONS, AND REPORTS TO WORKERS; INSPECTIONS

§ 19.2 [Amended]

8. Section 19.2 is amended by adding "61," following "40, 60."

§ 19.3 [Amended]

9. In § 19.3, paragraph (d) is amended by adding "61," following "40, 60."

PART 20—STANDARDS FOR PROTECTION AGAINST RADIATION

§ 20.2 [Amended]

10. Section 20.2 is amended by adding "61," following "40, 60."

§ 20.3 [Amended]

11. In § 20.3, paragraph (a)(9) is amended by adding "61," following "40, 60."

12. In § 20.301, paragraph (a) is amended by adding "61," following "40, 60," and paragraph (b) is revised to read as follows:

§ 20.301 General requirement.

* * * * *

(b) As authorized under § 20.302 or Part 61 of this chapter; or

* * * * *

§ 20.302 [Amended]

13. In § 20.302, paragraph (b) is removed.

14. A new § 20.311 is added to read as follows:

§ 20.311 Transfer for disposal and manifests.

(a) *Purpose.* The requirements of this section are designed to control transfers and establish a manifest tracking system and supplement existing requirements concerning transfers and recordkeeping.

(b) Each shipment of radioactive waste to a licensed land disposal facility must be accompanied by a shipment manifest that contains the name, address, and telephone number of the person generating the waste as well as the name, address, and telephone number of the person transporting the waste to the land disposal facility. The manifest must also indicate as completely as practicable: the type of waste; the waste volume and mass; radionuclide identity and concentration; total radioactivity; and chemical form. The solidification agent must be specified. Wastes classified as Class A segregated, Class B stable, or Class C intruder in § 61.55 of this part chapter must be clearly identified as such in the manifest. The total quantity of noted isotopes identified in Table 1, Part 61 of this chapter must be shown.

(c) Each manifest must include a certification by the waste generator that the transported materials are properly classified, described, packaged, marked, and labeled and are in proper condition for transportation according to the applicable regulations of the Department of Transportation and the Commission. An authorized representative of the waste generator shall sign and date the manifest.

(d) Any generating licensee who transfers radioactive waste to a land disposal facility or a licensed waste collector or processor shall:

(1) Prepare all wastes so that the waste is classified according to § 61.55 and meets the waste characteristics requirements in § 61.56 of this chapter;

(2) Label each package of waste to identify whatever it is, Class A segregated, Class B stable, or Class C intruder waste, in accordance with § 61.55 of this chapter;

(3) Conduct a quality assurance program to assure compliance with §§ 61.55 and 61.56 of this chapter; the program must include management audits;

(4) Prepare shipping manifests to meet the requirements of §§ 20.311 (b) and (c) of this part;

(5) Forward a copy of the manifest to the intended recipient, at the time of shipment;

(6) Include one copy of the manifest with the shipment;

(7) Retain a copy of the manifest until receipt of waste is acknowledged; and,

(8) Investigate late or missing shipments or any part of a shipment in accordance with paragraph (h) of this section.

(e) Any waste collector licensee who handles only prepackaged waste shall:

(1) Acknowledge receipt of the waste from the generator within one week of receipt;

(2) Prepare a new manifest to reflect consolidated shipments; the new manifest shall serve as a listing or index for the detailed generator manifests. Copies of the generator manifests shall be a part of the new manifest. The collector licensee shall certify that nothing has been done to the waste which would invalidate the generator's certification;

(3) Forward a copy of the new manifest to the land disposal facility operator at the time of shipment;

(4) Include the new manifest with the shipment to the disposal site;

(5) Retain a copy of the manifest until receipt of waste is acknowledged; and

(6) Investigate late or missing shipments or any part of a shipment in accordance with paragraph (h) of this section.

(f) Any licensed waste processor who treats or repackages wastes shall:

(1) Acknowledge receipt of the waste from the generator within one week of receipt;

(2) Prepare a new manifest that meets the requirements of paragraphs (b) and (c) of this section. Preparation of the new manifest reflects that the processor is responsible for the waste;

(3) Prepare all wastes so that the waste is classified according to § 61.55 and meets the waste characteristics requirements in § 61.56 of this chapter;

(4) Label each package of waste to identify whatever it is, Class A segregated, Class B stable, or Class C intruder waste, in accordance with § 61.55 of this chapter;

(5) A quality assurance program shall be conducted to assure compliance with §§ 61.55 and 61.56 of this chapter. The program shall include management audits;

(6) Forward a copy of the new manifest to the disposal site operator or waste collector at the time of shipment;

(7) Include the new manifest with the shipment;

(8) Retain copies of original manifests and new manifests until receipt of the wastes is acknowledged; and

(9) Investigate late or missing shipments in accordance with paragraph (h) of this section.

(g) The land disposal facility operator shall:

(1) Acknowledge to the shipper receipt of the waste within one week of receipt. The shipper to be notified is the licensee who last possessed the waste and transferred the waste to the operator;

(2) Following receipt and acceptance of a shipment of radioactive waste accompanied by a manifest, record on the shipment manifest the date of receipt of the waste, the date of disposal of the waste, the location in the disposal site, the condition of the waste packages as received, and any evidence of leaking or damaged packages or radiation or contamination levels in excess of limits specified in DOT and Commission regulations. The licensee shall also briefly describe any repackaging operations of any of the waste packages included in the shipment, plus any other information required by the Commission as a license condition;

(3) Sign, date, and certify that the transported materials have been received, classified, handled, stored, and disposed of in compliance with Commission regulations and all license conditions;

(4) Maintain copies of all completed manifests until the Commission authorizes their disposition at transfer; and

(5) Notify the shipper (i.e., the generator, the collector, or processor) and the Director of the nearest Commission Inspection and Enforcement Regional Office listed in Appendix D of this part when a shipment has not arrived within 60 days after the advance manifest was received.

(h) Late or missing shipments must:

(1) Be investigated by the shipper if the shipper has not received notification of receipt within 20 days after transfer; and

(2) Be traced and reported. The investigation shall include tracing the shipment and filing a report with the nearest Commission Inspection and Enforcement Regional Office listed in Appendix D of this part. Each licensee who conducts a trace investigation shall file a written report with the nearest Commission's Regional office within 2 weeks of completion of the investigation.

15. In § 20.401, paragraphs (b) and (c)(3) are revised to read as follows:

§ 20.401 Records of surveys, radiation monitoring, and disposal.

* * * * *

(b) Each licensee shall maintain records in the same units used is this part, showing the results of surveys required by § 20.301(b), monitoring required by §§ 20.205(b) and 20.205(c) and disposals made under §§ 20.302, 20.303, deleted § 20.304,[1] and Part 61 of this chapter.

(c) * * *

(3) Records of disposal of licensed materials made pursuant to §§ 20.302, 20.303, deleted § 20.304[1]; and Part 61 of this chapter are to be maintained until the Commission authorizes their disposition.

* * * * *

16. Section 20.408 is amended by adding a new paragraph (a)(5) to read as follows:

§ 20.408 Reports of personnel monitoring on termination of employment or work.

(a) * * *

(5) Receive radioactive waste from other persons for disposal under part 61 of this chapter.

* * * * *

PART 21—REPORTING OF DEFECTS AND NONCOMPLIANCE

§ 21.2 [Amended]

17. Section 21.2 is amended by inserting "61", after "40, 60," in the third line, and after "50, 60" in the final line.

§ 21.3 [Amended]

18. In § 21.3, paragraphs (a)(3), (a) (a-1)(1), (a) (a-1)(2), and (k) are amended by adding "61," after "50, 60."

§ 21.21 [Amended]

19. Section 21.21 is amended by adding "61,'" after "50, 60," in paragraphs (b)(1)(i) and (b)(1)(ii).

PARTS 30—RULES OF GENERAL APPLICABILITY TO LICENSING OF BYPRODUCT MATERIAL

20. Section 30.11(c) is revised to read as follows:

§ 30.11 Specific exemptions.

* * * * *

(c) Except as specifically provided in Part 61 of this Chapter, any licensee is exempt from the requirements of this part to the exent that its activities are subject to the requirements of Parts 60 and 61 of this chapter.

21. In § 30.32, paragraph (f) is amended to read as follows:

§ 30.32 Application for specific licenses.

* * * * *

(f) An application for a license for the conduct of any activity which the Commission determines will significantly affect the quality of the environment shall be filed at least 9 months to commencement of construction of the plant or facility in which the activity will be conducted and shall be accompanied by any Environmental Report required pursuant to Part 51 of this chapter.

22. In § 30.33, paragraph (a)(5) is revised to read as follows:

§ 30.33 General requirements for issuance of specific licenses.

(a) * * *

(5) In the case of an application for a license for the conduct of any activity which the Commission determines will significantly affect the quality of the environment, the Director of Nuclear Material Safety and Safeguards or his designee, before commencement of construction of the plant or facility in which the activity will be conducted, on the basis of information filed and evaluations made pursuant to Part 51 of this chapter, has concluded, after weighing the environmental, economic technical, and other benefits against environmental costs and considering available alternatives, that the action called for is the issuance of the proposed license, with any appropriate conditions to protect environmental values. Commencement of construction prior to such conclusion shall be grounds for denial of a license to receive and possess byproduct material in such plant or facility. As used in this paragraph the term "commencement of construction" means any clearing of land, excavation, or other substantial action that would adversely affect the environment of a site. The term does not mean site exploration, necessary roads for site exploration, borings to determine foundation conditions, or other preconstruction monitoring or testing to establish background information related to the suitability of the site or the protection of environmental values.

* * * * *

PART 40—LICENSING OF SOURCE MATERIAL

23. In § 40.14, paragraph (c) is revised to read as follows:

§ 40.14 Specific exemptions.

* * * * *

(c) Except as specifically provided in Part 61 of this chapter any licensee is exempt from the requirements of this part to the extent that its activities are subject to the requirements of Parts 60 and 61 of this chapter.

24. In § 40.31, paragraph (f) is revised to read as follows:

§ 40.31 Applications for specific licenses.

* * * * *

(f) An application for a license to possess and use source material for uranium milling, production of uranium hexafluoride, or for the conduct of any other activity which the Commission determines will significantly affect the quality of the environment shall be filed at least 9 months prior to commencement of construction of the plant or facility in which the activity will be conducted and shall be accompanied by any Environmental Report required pursuant to Part 51 of this chapter.

* * * * *

25. In § 40.32, paragraph (e) is revised to read as follows:

§ 40.32 General requirements for issuance of specific licenses.

* * * * *

(e) In the case of an application for a license to possess and use source and byproduct material for uranium milling, production of uranium hexafluoride, or for the conduct of any other activity which the Commission determines will significantly affect the quality of the environment, the Director of Nuclear Material Safety and Safeguards or his designee, before commencement of construction of the plant or facility in which the activity will be conducted, on the basis of information filed and evaluations made pursuant to Part 51 of this chapter, has concluded, after weighing the environmental, economic, technical and other benefits against environmental costs and considering available alternatives, that the action called for is the issuance of the proposed license, with any appropriate conditions to protect environmental values. Commencement of construction prior to such a conclusion shall be grounds for denial of a license to possess and use source and byproduct material in such plant or facility. As used in this paragraph the term 'commencement of construction" means any clearing of land, excavation, or other substantial action that would adversely affect the environment of a site. The term does not mean site exploration, necessary roads for site exploration, borings to determine foundation conditions, or other preconstruction monitoring or testing to establish background information related to the suitability of the site or the protection of environmental values.

* * * * *

PART 51—LICENSING AND REGULATORY POLICY AND PROCEDURES FOR ENVIRONMENTAL PROTECTION

26. In § 51.5, paragraphs (a)(6) and (b)(4)(iii) are revised, paragraph (b)(6) is amended by inserting "61" following "50, 60,", and (d)(3) is amended by inserting "61" following "50, 60." The revised paragraphs read as follows:

§ 51.5 Actions requiring preparation of environmental impact statements, negative declarations, environmental impact appraisals; actions excluded.

(a) * * *

(6) Issuance of a license authorizing receipt and disposal of radioactive waste from other persons under Part 61 of this chapter.

* * * * *

(b) * * *

(4) * * *

(iii) Authorizing receipt and disposal of radioactive waste from other persons under Part 61 of this chapter.

* * * * *

§ 51.40 [Amended]

27. In § 51.40, paragraph (c) is amended by inserting "61" after "30, 40."

PART 70—DOMESTIC LICENSING OF SPECIAL NUCLEAR MATERIAL

28. In § 70.14, paragraph (c) is amended to read as follows:

§ 70.14 Specific exemptions.

* * * * *

(c) Except as specifically provided in Part 61 of this chapter, any licensee is exempt from the requirements of the regulations in this part to the extent that its activities are subject to the requirements of Parts 60 and 61 of this chapter.

29. In § 70.21 paragraph (f) is revised to read as follows:

§ 70.21 Filing.

* * * * *

(f) An application for a license to possess and use special nuclear material for processing and fuel fabrication, scrap recovery or conversion of uranium hexafluoride, or for the conduct of any other activity which the Commission determines will significantly affect the quality of the environment shall be filed at least 9 months prior to commencement of constrution of the plant or facility in which the activity will be conducted, and shall be accompanied by an Environmental Report required under Part 51 * * * of this chapter.

* * * * *

30. In § 70.23 paragraph (a)(7) is revised to read as follows:

§ 70.23 Requirements for the approval of applications.

(a) * * *

(7) Where the proposed activity is processing and fuel fabrication, scrap recovery, conversion of uranium hexafluoride, or any other activity which the Commission determines will significantly affect the quality of the environment, the Director of Nuclear Material Safety and Safeguards or his designee, before commencement of construction of the plant or facility in which the activity will be conducted, on the basis of information filed and evaluations made pursuant to Part 51 of this chapter, has concluded, after weighing the environmental, economic, technical, and other benefits against environmental costs and considering available alternatives, that the action called for is the issuance of the proposed license, with any appropriate conditions to protect environmental values. Commencement of construction prior to such conclusions shall be grounds for denial to possess and use special nuclear material in such plant or facility. As used in this paragraph the term "commencement of construction" means any clearing of land, excavation, or other substantial action that would adversely affect the environment of a site. The term does not mean site exploration, necessary roads for site exploration, borings to determine foundation conditions, or other preconstruction monitoring or testing to establish background information related to the suitability of the site or the protection of environmental values.

* * * * *

PART 73—PHYSICAL PROTECTION OF PLANTS AND MATERIALS

31. In § 73.1, paragraph (b)(1)(iii) is revised to read as follows:

§ 73.1 Purpose and scope.

* * * * *

(b) * * *

(1) * * *

(iii) the physical protection of special nuclear material by any person who, pursuant to the regulations in parts 61 and 70 of this chapter, possesses or uses at any site or contiguous sites subject to the control by the licensee, formula quantities of strategic special nuclear material or special nuclear material of moderate strategic significance or special nuclear material of low strategic significance.

* * * * *

PART 170—FEES FOR FACILITIES AND MATERIALS LICENSES AND OTHER REGULATORY SERVICES UNDER THE ATOMIC ENERGY ACT OF 1954, AS AMENDED*

32. Section 170.2 is revised to read as follows:

§ 170.2 Scope.

Except for persons who apply for or hold the permits, licenses, or approvals exempted in § 170.11, the regulations in this part apply to a person who is an applicant for, or holder of, a specific byproduct material license issued pursuant to Parts 30 and 32–35 of this chapter, a specific source material license issued pursuant to Part 40 of this chapter, a specific materials license issued under Part 61 of this chapter, a specific special nuclear material license issued pursuant to Part 70 of this chapter, a specific approval of spent fuel casks and shipping containers issued pursuant to Part 71 of this chapter, a specific request for approval of sealed sources and devices containing byproduct material, source material, or special nuclear material, or a production or utilization facility construction permit and operating license issued pursuant to Part 50 of this chapter, to routine safety and safeguards inspections of a licensed person, to a person who applies for approval of a reference standardized design of a nuclear steam supply system or balance of plant, for review of a facility site prior to the submission of an application for a construction permit, for review of a standardized spent fuel facility design, and for a special project review, which the Commission completes or makes whether or not in conjunction with a license application on file or which may be filed.

Note.—Amendments to all parts are issued pursuant to citations of authority presently codified or, in the case of 10 CFR Part 61, as set out after the list of sections in the new Part 61.

Dated at Washington, D.C., this 21st day of July 1981.

For the U.S. Nuclear Regulatory Commission.

Samuel J. Chilk,
Secretary of the Commission.

[FR Doc. 81-21734 Filed 7-23-81; 8:45 am]
BILLING CODE 7590-01-M

NRC FORM 335 (7-77) U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC): NUREG-0782, Vol. 1

TITLE AND SUBTITLE (Add Volume No., if appropriate): Draft Environmental Impact Statement on 10 CFR Part 61: "Licensing Requirements for Land Disposal of Radioactive Waste", Summary

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S): NRC Staff

5. DATE REPORT COMPLETED: MONTH Sept. YEAR 1981

DATE REPORT ISSUED: MONTH Sept. YEAR 1981

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code): Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, DC 20555

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code): Same as 9.

10. PROJECT/TASK/WORK UNIT NO

11. CONTRACT NO

13. TYPE OF REPORT: Draft Environmental Impact Statement

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

The four volume draft environmental impact statement (DEIS) is prepared to guide and support publication of a proposed new regulation, 10 CFR Part 61, for the land disposal of low-level radioactive waste. The analysis in the DEIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design of disposal facilities, the method of operation of the facilities, institutional controls, financial assurances, and administrative and procedural requirements. From the analysis, four main performance objectives are established in the proposed regulation relating to (1) minimizing long-term social commitment and costs, (2) minimizing long-term environmental releases, (3) minimizing long-term impacts to humans potentially inadvertently intruding into disposed waste, and (4) assuring short-term operational safety. Based upon the analysis and overall performance objectives, a number of technical, financial, procedural, and administrative requirements are also developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
groundwater migration
inadvertent intrusion
10 CFR Part 61
waste form
financial assurances
institutional controls
radioactive waste
disposal technologies
cost-benefit analysis

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT: Unlimited

19. SECURITY CLASS (This report): Unclassified

20. SECURITY CLASS (This page): Unclassified

21. NO. OF PAGES: 68

22. PRICE: $

NRC FORM 335 (7-77)

Newman

NUREG-0782
Vol. 2

Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Main Report

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street., N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, transactions, and codes and standards. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

VOLUME II

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

List of Tables

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Figures

List of Preparers

The overall responsibility for the preparation of this draft environmental impact statement was assigned to the Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission. The statement was prepared with technical assistance from the firm of Dames and Moore, White Plains, New York.

Nuclear Regulatory Commission Staff

Preparers

R. Dale Smith, Chief
Low-Level Waste Licensing Branch

Paul H. Lohaus
Part 61 Task Leader

G. W. Roles
Part 61 EIS Project Manager

Kitty S. Dragonette

Mary Jo Seeman

Martin S. Weinstein

Contributors

Charles W. Bishop
Timothy C. Johnson
Robert D. MacDougall
Charles Nichols
George C. Pangburn
David L. Siefken
J. Wassler
Rex G. Wescott
Derek Widmayer

Special Contributors

Willste CRESS Central Dictation Unit

Etta Nicolet, Supervisor
Carolyn Holly
Pauline Rock
Alice Werner, Proofreader
Irene Suissa
Marguerite Wason

Robert Fonner, Attorney, Office of the Executive Legal Director
Patricia A. Smith, Contracts Specialist, Office of Administration
Jacqueline Newbury, Secretary, LLW Licensing Branch
Charlette W. Henry, Secretary, LLW Licensing Branch

Dames and Moore Staff

Others contributing significantly to this environmental impact statement included personnel of the firm of Dames and Moore, Inc. (D&M) of White Plains, New York. The D&M contribution was directed by Dr. Oktay I. Oztunali, who assumed this responsibility upon the untimely death of Alexander E. Aikens in the early stages of the project.

Principal D&M Contributors

Oktay I. Oztunali
Ralph E. Wild
Gary C. Ré
James J. Clancy
Kathryn E. Kelly

Other D&M Contributors

M. Salah Abdelhamid
Patricia Buchinsky
Dara F. Gray
Perry M. Moskowitz
Peter C. Newsom
C. Joseph Pitt
Estaban D. Picazo

Chapter 1

INTRODUCTION

1.1 PURPOSE, SCOPE, AND STRUCTURE OF STATEMENT

This environmental impact statement (EIS) addresses development of a new regulation, Part 61, to the U.S. Nuclear Regulatory Commission (NRC) rules in Title 10, Code of Federal Regulations to provide specific requirements for licensing the land disposal of low-level radioactive waste (LLW).

There are three principal purposes to the regulation being developed:

- o Establish general requirements for the land disposal of radioactive waste;
- o Establish the technical requirements for disposal of radioactive waste by near-surface disposal including limits on the form and content of waste to classify or to define which wastes are acceptable for near-surface disposal; and
- o Establish the administrative and procedural requirements which NRC will follow in licensing the land disposal of radioactive waste.

In this EIS, performance objectives are analyzed and presented for land disposal. Specific technical requirements are analyzed and presented for near-surface disposal methods--i.e., disposal that generally takes place within the top 15-20 meters of the earth's surface involving specific techniques such as shallow land burial, deeper burial and engineered designs and modifications. Finally, administrative, procedural, and financial requirements for licensing specific land disposal facilities are also developed and presented.

1.1.1 Purpose

NRC has a two-fold purpose in preparing this EIS. First, it is to fulfill NRC's responsibilities under the National Environmental Policy Act of 1969 (NEPA) (Ref. 1). Section 102(2)(c) of NEPA requires that an EIS be prepared by federal agencies for "major Federal actions significantly affecting the quality of the human environment..." NRC has determined that the promulgation of a new regulation governing the disposal of LLW constitutes such an action and that an EIS should therefore be prepared.

NRC has also prepared this EIS to demonstrate the decision process and bases applied in the establishment of technical requirements and licensing procedures to be included in the Part 61 regulation. It is the intent of NEPA to have federal agencies incorporate environmental values into the decisionmaking process at an early stage to assure a thorough consideration of such values. As will be shown in later chapters of this document, NRC has considered and analyzed alternative courses of action and requirements were selected with full consideration of environmental, health, and safety effects to current and future generations.

1.1.2 Scope

This EIS analyzes requirements for the land disposal of radioactive waste. As will be discussed in greater detail in Chapter 2, there is a large range in alternative disposal methods which can be applied in the disposal of LLW including deep space, ocean disposal, and a range of land-based methods. It is not possible to develop one regulation dealing with such a large variation in disposal technologies. Thus, Part 61 will apply and this EIS will analyze requirements for the land disposal of waste. Requirements for ocean disposal are a responsibility of the EPA. Space disposal, although technically feasible, is not developed to the point of routine technical and economic application.

This EIS is not a generic EIS in that it does not attempt to analyze all of the issues that are involved in the disposal of LLW. Rather, it is specific to providing a balanced decision analysis leading to the establishment of the technical requirements and procedures for licensing the disposal of LLW. Only issues that are germane to this decision process are analyzed and considered. Section 1.4 of this chapter summarizes these issues.

NRC had initially planned to develop and issue a regulation that would apply only to shallow land burial followed by amendments that would apply to other specific alternative land-based disposal methods. Based on initial work in scoping and preparing this EIS, NRC has expanded the scope of this initial rulemaking action to include determination of overall performance objectives expected in land disposal; specific technical requirements for the disposal of waste "near surface" by such means as shallow burial, engineered designs and modifications and deeper burial; and general requirements for disposal of waste by other methods (e.g., deep-mined cavity or other very deep disposal). The development of specific technical requirements for deep mined cavities or for other very deep disposal methods will be considered at a later time through a separate rulemaking. The specific aspects of LLW disposal that are examined and analyzed to determine the requirements for near-surface disposal include the form and content of waste; institutional control and surveillance of a disposal facility after closure; natural site characteristics; disposal facility design and operations; and financial assurance. Administrative and procedural requirements for licensing the land disposal of LLW are also examined. Finally, this EIS also examines and establishes a classification or definition of which wastes are acceptable for disposal by near-surface disposal methods (and which wastes are not and must be disposed of by other methods).

1.1.3 Structure of the EIS

This EIS has been prepared in accordance with requirements of the National Environmental Policy Act (NEPA) and following Council on Environmental Quality (CEQ) regulations (Ref. 2) for preparation of environmental impact statements and NRC implementing regulations set out in Title 10, Code of Federal Regulations, Part 51, "Licensing and Regulatory Policy and Procedures for Environmental Protection." Both existing NRC requirements and those set out in a

Notice of Proposed Rulemaking to amend 10 CFR Part 51 to implement new CEQ regulations (Ref. 3) have been consulted in the preparation of this statement.

The EIS is divided into ten formal chapters which are listed and summarily described in the following paragraphs.

Chapter 1 - "Introduction" discusses the purpose, scope, and structure of the EIS, describes the proposed action and the need for it, reviews the scoping process used to focus the EIS, and sets out the specific issues involving radioactive waste disposal that will be addressed in this statement.

Chapter 2 - "Development of Regulations for LLW Disposal" presents the strategy NRC has followed in developing regulations for LLW disposal and presents and resolves three issues: the type of requirements to be developed, alternative disposal methods, and approach to classification of LLW.

Chapter 3 - "Description of the Affected Environment and Approach Followed in Preparing this EIS" describes the environment experiencing direct and indirect impacts and describes how, for purposes of analysis in this EIS, NRC developed a base of data about the environment and developed impact measures that can be applied in deciding the performance objectives and technical requirements that should be applied in the disposal of LLW.

Chapter 4 - "Presentation and Analysis of Alternatives-Intruder" presents an analysis of LLW disposal to determine pathways of human exposure thru inadvertent intrusion, analyzes the "no action alternative" presenting typical costs and impacts to an inadvertent intruder from LLW disposal as it has typically been carried out; analyzes a range of alternatives that can be applied in the design, operation, institutional control, and form of waste to reduce the impacts to an inadvertent intruder; presents and analyzes a range of numerical performance objectives and technical requirements to assure an adequate level of safety in LLW disposal; and selects a preferred performance objective and technical requirements.

Chapter 5 - "Presentation and Analysis of Alternatives-Long-Term Environmental Protection" analyzes long-term environmental pathways of release; analyzes the "no action alternative" presenting typical costs and impacts from environmental releases; analyzes a range of alternatives that can be applied to mitigate the impacts; presents and analyzes alternatives performance objectives and technical requirements for long-term environmental protection; and selects a preferred performance objective and technical requirements.

Chapter 6 - "Operational Safety" analyzes safety during the operation of a near-surface disposal facility including potential releases from accidents and waste processing at a central waste processing facility colocated with the disposal facility and sets out requirements directed at assuring safety during operations.

Chapter 7 - "Classification of Waste for Near-Surface Disposal" collectively ties all of the preferred technical requirements together to present a classification of waste for near-surface disposal, i.e., defines several categories of waste based on the type, form, and concentration of various nuclides in waste and the requirements that should be applied in the disposal of each category. It also identifies wastes which would generally not be acceptable for near-surface disposal.

Chapter 8 - "Regulatory Program for LLW Disposal" reviews existing administrative and procedural requirements followed and applied by the NRC in licensing LLW disposal facilities and presents changes to these requirements.

Chapter 9 - "Financial Assurances for Closure, Postclosure, and Institutional Control" reviews the need for financial assurance requirements; presents and analyzes alternatives considered; and selects preferred requirements to assure adequate funds will be available for closure, postclosure, and institutional control.

Chapter 10 - "Environmenal Consequences of Part 61" presents the typical and unmitigated impacts of the new Part 61 rule including analysis of the disposal of waste on a regional basis following the preferred technical requirements identified in this EIS.

A series of Appendices which are being published as a separate volume contain the details of the assumptions, analysis methodology, computer programs, and detailed listing of results. Following is a listing of the Appendices.

Appendix A - "Reserved for Staff Analysis--Comments on Draft EIS and Proposed Part 61 Rule"
Appendix B - "Reserved for Public Comments on Draft EIS and Proposed Part 61 Rule"
Appendix C - "Public Participation in the Development of the LLW Disposal Regulation"
Appendix D - "Low-Level Waste Sources and Processing Options"
Appendix E - "Description of a Reference Near-Surface Disposal Facility"
Appendix F - "Alternative Near-Surface Disposal Technologies"
Appendix G - "LLW Disposal Impacts Analysis Methodology"
Appendix H - "Alternatives Analysis Codes"
Appendix I - "NRC Branch Technical Position-Low-Level Waste Burial Ground Site Closure and Stabilization"
Appendix J - "Regional Case Studies"
Appendix K - "Financial Requirements for Closure, Postclosure and Active Institutional Control for a Disposal Facility"
Appendix L - "Reserved for Final EIS"
Appendix M - "Potential Long-Term Impact Other than Ground-Water Migration and Inadvertent Intrusion"
Appendix N - "Analysis of Existing Recommendations, Regulations, and Guides"
Appendix O - "Reserved for Final EIS"
Appendix P - "Reserved for Final EIS"
Appendix Q - "Calculation of Preoperational, Operational, Closure, and Active Institutional Control Costs"

1.2 NEED FOR AND DESCRIPTION OF THE PROPOSED ACTION

This section is designed to acquaint the reader with basic information on commercial waste disposal as it exists today and then, drawing upon this information, demonstrate the need for a comprehensive LLW regulation. The section also contains a brief description of the proposed action.

1.2.1 Background to Commercial LLW Disposal

The term "low-level waste" serves as a general term for a very wide range of radioactive waste. Any industry, hospital, medical, educational, or research institution, private or government laboratory, nuclear power plant, and other facilities forming part of the nuclear fuel cycle (e.g., a fuel fabrication plant) utilizing radioactive material as a part of their operational activities generates so-called low-level radioactive waste just as they generate other types of hazardous and nonhazardous waste. LLW consists of the radioactive materials themselves and materials which have been in contact with radioactive material and are contaminated or suspect of being contaminated.

Presently there are more than 20,000 companies, institutions, laboratories, and government facilities licensed by the NRC or Agreement States to use radioactive materials as a normal part of their day-to-day activities and most of these users generate some form of low-level radioactive waste which must be disposed of. Because of the wide range in the type of activities using these materials and the wide range in specific purposes of application, LLW is generated in a wide range of waste types, forms, and amounts. It ranges from suspect trash (e.g., laboratory wipes merely suspected of being contaminated) and hospital waste containing small quantities of short-lived radiopharmaceuticals to higher activity reactor filter sludges and sealed cobalt teletherapy sources. Currently about 85,000 m^3 (3 million ft^3) of commercial LLW is generated annually. Based on projections of LLW volume prepared by NRC for the 36 basic waste streams considered in this EIS, about 3.62 million m^3 (128 million ft^3) will be generated during the period 1980-2000. Of this, about 65% of the waste will be generated by fuel cycle sources and 35% by nonfuel cycle sources. Institutional generators will account for about 19% of the nonfuel cycle sources.

For most of the LLW that is generated in the U.S., the disposal process consists of three steps: processing and packaging; transport; and disposal. With regard to the first of these steps, most LLW, in its generated form, is placed in a U.S. Department of Transportation (DOT) shipping container and transported to a licensed commercial disposal facility for disposal. In other cases the waste may be further processed to reduce its volume or change its form (e.g., solidification of liquid wastes with cement) at which point it is placed inside a DOT-approved shipping container and shipped for disposal. (In some cases the type, form, and quantity of waste generated is such that the licensee can dispose of it directly under specific provisions of 10 CFR Part 20, e.g., discharge to the sanitary sewer system.)

In addition to those licensees who generate LLW, there are a number of licensed companies involved in the pickup, transport, and delivery of packaged LLW to licensed disposal facilities for disposal. In some cases, these companies also provide additional services including supply of packaging, preparation of waste for shipment, and solidification of liquids. These companies generally pick up waste at customer facilities, consolidate individual waste packages into larger shipments, assume responsibility for the waste, and transport it to the disposal facility. A waste generator not using the services of such waste collectors will hire and consign the waste to a registered common or contract carrier for transport to the disposal facility. In this case the shipper retains responsibility for the waste.

Upon receipt of packaged LLW by a licensed commercial disposal site operator, it is disposed of by a method known as shallow land burial (SLB). This method of waste disposal consists of placing packaged waste into trenches that are about 150 m long by 30 m wide by 8 m deep. The trenches are backfilled with soil material excavated from the trench during construction, capped, and mounded to facilitate precipitation runoff.

1.2.2 Brief History of LLW Disposal

The disposal of commercial LLW by shallow land burial generally followed from the practices and procedures utilized by the Atomic Energy Commission (AEC) at national laboratories involved in atomic energy research and development and defense programs (Ref. 4). Activities in the programs involving use of radioactive materials generated quantities of radioactive waste and means had to be developed for their disposal.

Two principal methods of disposal were utilized: SLB and ocean disposal. The practice of SLB was quickly adopted as the preferred disposal practice. This technique could be utilized near the point where the waste was being generated, avoiding unnecessary transportation which might jeopardize the security of the project in the event of a transportation accident. In addition, SLB proved to be a fairly cost-effective technique as it employed practices commonly used in sanitary landfill operations and did not require unusual equipment or construction techniques.

With the growth of commercial applications, the AEC announced in 1960 that regional land burial sites for commercial LLW should be established on federal- or state-owned land and that the sites should be operated by private contractors subject to government licensing authority. With this announcement, the AEC indicated that its disposal sites would only be available for commercial use until adequate disposal capacity was established in the private sector. As an interim measure, pending designation of regional commercial waste sites, the AEC also announced that disposal sites at Idaho Falls, Idaho and Oak Ridge, Tennessee would continue to accept commercial wastes for disposal.

At the same time, the AEC also initiated a phase-out of sea disposal operations by placing a moratorium on the issuance of new sea disposal licenses. Existing licenses remained in effect and were phased out. The last disposal at sea took place in June 1970.

In February 1961, the AEC established a regulatory program for licensing the commercial operation of land burial sites on federal or state government-owned land. The regulations in existence at that time set out no specific technical criteria for site selection, design, operation, and closure although general considerations regarding site hydrology, geology, and other factors that should be addressed were identified. In September 1962, the AEC licensed the first commercial land burial site at Beatty, Nevada and, during the period 1962-1971, five additional commercial sites were licensed by the AEC or Agreement States resulting in a regional distribution of commercial disposal sites. These six sites were spread geographically throughout the United States and located near Richland, Washington (sited on the Hanford Reservation); Beatty, Nevada; Sheffield, Illinois; Maxey Flats, Kentucky; West Valley, New York; and Barnwell, South Carolina. In May 1962, the AEC withdrew its program of interim acceptance of commercial waste at Idaho Falls and Oak Ridge.

The DOE has operated 14 sites throughout the country for the disposal of wastes generated from defense programs and DOE research and development activities. A discussion of the characteristics and problems of the commercial and DOE sites has been extensively studied and is well-documented in the literature. Presently only three commercial sites remain open and two companies are involved in their operation: Chem-Nuclear Systems, Inc. (Barnwell, South Carolina) and U.S. Ecology, Inc. (Beatty, Nevada and Richland, Washington). Table 1.1 lists the six commercial sites, their respective operators, and current status.

Table 1.1 Commercial Waste Disposal Sites

Location	Operator	Originally Licensed By (year)	Currently Licensed By	Operational Status
Beatty, Nevada	U.S. Ecology, Inc.	AEC (1962)	State	Open
Maxey Flats, Kentucky	U.S. Ecology, Inc.	Kentucky (1962)	State	Closed
West Valley, New York	Nuclear Fuel Services, Inc.	New York (1963)	State	Closed
Richland, Washington	U.S. Ecology, Inc.	AEC (1965)	State and NRC*	Open
Sheffield, Illinois	U.S. Ecology, Inc.	AEC (1967)	NRC	Closed
Barnwell, S. Carolina	Chem-Nuclear Systems, Inc.	South Carolina (1971)	State and NRC*	Open

*NRC licenses only special nuclear material.

1.2.3 Federal and State Responsibilities in Commercial LLW Disposal

There are five key federal agencies that administer programs regarding the management and disposal of LLW. These include the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS) in the Department of Interior, the Department of Energy (DOE), and the Department of Transportation (DOT).

The Nuclear Regulatory Commission (NRC) was established by the Energy Reorganization Act of 1974. This Act abolished the Atomic Energy Commission (AEC) and transferred all of its licensing and related regulatory functions assigned by the Atomic Energy Act of 1954 to NRC. Prior to 1974, the AEC had not only regulatory and licensing responsibilities, but also research and development functions with respect to atomic energy and related disciplines. The Energy Reorganization Act of 1974 split the AEC into two separate organizations: the NRC and the Energy Research and Development Administration (ERDA). The functions of ERDA have since been incorporated into the Department of Energy which carries out federal responsibilities for the research, development, and transfer of LLW disposal technology to commercial industry.

NRC has the responsibility in the United States of regulating and licensing the commercial and nondefense governmental use of source, byproduct, and special nuclear material. This responsibility extends to licensing commercial disposal of LLW in licensed facilities. NRC carries out its responsibilities in compliance with overall federal radiation protection guidance and environmental standards established by the Environmental Protection Agency. EPA was charged with this responsibility in the Reorganization Plan Number Three of 1970. The U.S. Geological Survey is responsible for basic research in the geological sciences and development of basic data for application in the development of criteria and to provide technical advice in the assessment of specific disposal sites. The U.S. Department of Transportation has the primary responsibility for regulating waste containers, transport vehicles, and other aspects of the interstate transport of radioactive waste.

Existing NRC regulations for commercial LLW disposal in licensed disposal facilities are principally contained in a few paragraphs in 10 CFR Part 20 (§20.302). The requirements mainly describe in general terms the type of information to be included in an application for a disposal facility and require that LLW disposal facilities must be sited on land owned by the state or federal government. In addition to disposal of waste at commercially operated shallow land burial facilities, provisions of 10 CFR Part 20 provide other means that licensees may use to dispose of waste directly. These include discharge to the sanitary sewer system (§20.303), release to the air and water (§20.106), burial in the soil or other means of disposal upon specific license approval (§20.302), and treatment or disposal by incineration (§20.305). The NRC also recently adopted amendments to Part 20 (§20.306) that provide for routine disposal of carbon-14 and tritium in concentrations less than 0.05 μCi/gm (microcurie/gram) when contained in animal carcass and liquid scintillation cocktail waste.

Other NRC regulations, Part 30 ("Rules of General Applicability to Domestic Licensing of Byproduct Material"), Part 40 ("Domestic Licensing of Source Material"), and Part 70 ("Domestic Licensing of Special Nuclear Material")--apply to possession of licensed material by a disposal facility licensee. Part 2 ("Rules of Practice for Domestic Licensing Proceedings") contains general requirements for NRC licensing proceedings. Part 51 ("Licensing and Regulatory Policy and Procedures for Environmental Protection") contains requirements for compliance with the National Environmental Policy Act of 1969 (NEPA). Under the existing regulatory framework for LLW disposal licensing, regulatory requirements for a potential disposal facility licensee are not centralized, systematic, or readily identified.

In discharging its responsibilities, NRC is empowered by the Atomic Energy Act to relinquish part of its regulatory authority over source, byproduct, and special nuclear material to the states. Under Section 274 of the Act, before the NRC enters into such an agreement, the state must have a radiation control program that is compatible with NRC's, and the state's program must be judged adequate by NRC to protect the public health and safety. Currently, there are 26 such Agreement States. To the extent that a new regulation represents a change in NRC's radiation protection programs for source, byproduct, and special nuclear material, it is necessary that the Agreement States cooperate in the formulation of compatible regulations and revise their existing regulations as necessary. Current NRC regulations regarding NRC's relationship with the Agreement States are contained in 10 CFR Part 150.

Licensing of commercial LLW disposal facilities is part of the NRC's authority which may be assumed by an Agreement State. Of the six commercial disposal facilities which have operated in the United States, five of these facilities are located in Agreement States and are principally regulated by the Agreement States (See Table 1.1).

1.2.4 Need for Action

As mentioned earlier, the AEC established a regulatory program for licensing the commercial operation of land disposal sites in February 1961. No detailed technical requirements for site selection, design, operation, and closure were, however, established (Ref. 4). The following considerations were applied by the AEC and Agreement States in licensing the existing commercial disposal sites:

- A written commitment must be obtained from a government body or a responsible official that a state or federal agency would assume control over the burial site in the event of default or abandonment of the site by the commercial operator. The site must be located on land owned by the federal or state government.

- The geological or hydrological characteristics of the site must be such that waste material is contained in a manner that will not endanger public health or safety and that migration of radioactivity from the site is unlikely.

- The waste must be in solid form before burial. Liquid waste must be solidified or immobilized to minimize the potential for migration.

- The burial ground operator must establish and conduct an environmental monitoring program. To determine whether migration has occurred, operators must establish a baseline of radioactivity that exists in the environment before any waste was buried. The monitoring program must be continued to detect radioactivity increases beyond those original levels. Increases must be reported to the appropriate regulatory agency, which then analyzes the possible significance.

- The packages in which wastes are transported must comply with appropriate federal standards. Packaging is designed to provide protection during transportation and handling. Although packaging would provide a primary barrier, the packaging and form of the waste were not relied upon nor expected to provide any significant waste containment after burial. The geology of the site was solely to be relied upon for containment.

In the late 1960s and early 1970s difficulties were encountered at some of the commercial and AEC sites relating to management of precipitation collecting in completed disposal trenches and releases of small concentrations of radioactivity. At the commercial sites, the difficulties were principally evident at the Maxey Flats, Kentucky and West Valley, New York sites. The problems were predominately attributed to three factors: (1) the trench cap or covering over the trench was of a higher permeability than the surrounding soil which allowed precipitation to enter and collect in trenches; (2) disposal trenches were completed when they contained appreciable quantities of rainwater; and (3) the compressible, degradable, unstable nature of the waste being buried led to subsidence of the trench cap creating pathways for precipitation to readily enter the trenches. These factors led to the filling of trenches with water and to small releases of radioactivity through surface and ground-water pathways.

Studies and corrective actions were initiated at the sites. Trenches were pumped to remove the water, and trench leachates were treated through an evaporator at Maxey Flats and a liquid waste treatment system at West Valley. Measures were also taken to recap and stabilize trenches to reduce future water infiltration. Results of monitoring programs and studies at the sites showed that although releases of radioactivity had occurred, they were low and presented no hazard to the public health and safety (Refs. 5 and 6). The primary experience gained was that the compressible, degradable, unstable nature of the waste disposed of, coupled with site conditions, was leading to unstable site conditions requiring active maintenance for uncertain periods of time at high costs. Funds being collected for postoperational activities were also inadequate to cover the potential long-term costs involved (particularly the long-term maintenance costs involved) in caring for the sites over the long term. These sites are presently closed and may require continued active maintenance for many years to assure stability.

Similar problems were experienced at the Sheffield, Illinois site where compressible unstable wastes have created an unstable site condition where stabilization action and potential long-term maintenance is required. Funds collected by the state for this purpose have also proved insufficient to cover the estimated costs. This site is presently closed and is the subject of an ASLB hearing regarding conditions for final closure of the site.

Problems of a different nature have occurred at the Beatty, Nevada site. Over a period of several years, employees removed containers and certain waste materials (e.g., contaminated tools) for personal offsite use. These materials were removed from the site in violation of federal and state regulations and license conditions. Based on extensive surveys by both federal and state personnel, no public health and safety hazard was created by the illegal removal (Ref. 7). This incident pointed to the need for more attention to site security and controls in disposal facility operations.

More recent problems have involved a lack of attention to detail on the part of many waste generators relating to the form and content of waste shipped for disposal (Ref. 8). The shipment of leaking and damaged packages and improper waste forms resulted in the temporary shutdown of two of the three operating commercial sites. In addition, with the shutdown in three of the operating sites, an imbalance in the regional disposal facility capacity has resulted with most of the waste being generated in the east and most of the disposal capacity located in the west. Several actions have evolved in response to this. The South Carolina site is reducing the average monthly volume of waste it will accept to the average monthly volume received during 1977 (100,000 ft^3/month) (Ref. 9). A voter initiative was passed in the state of Washington to prohibit the receipt of out-of-state waste (except institutional waste) by July 1981 unless action is taken to form a regional state compact. This action was recently ruled unconstitutional and thus unenforceable by the U.S. District Court in Washington (Ref. 10). Congress also recently acted in this area by passing the "Low-Level Radioactive Waste Policy Act" (PL-96-573) which places the responsibility for assurance of adequate LLW disposal capacity on the states. The law stresses the regional solution to adequate LLW disposal capacity.

Also, in 1976, an NRC Task Force was created to review programs used by the NRC and state governments to regulate disposal of commercial low-level waste. A document entitled "NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds" (NUREG-0217) was published in March 1977 (Ref. 4). In the report the Task Force made a number of recommendations regarding federal and state regulation of LLW disposal and other related issues affecting commercial burial ground regulation and operation. These recommendations included development of a specific regulatory program for low-level waste disposal including development of more comprehensive regulations, standards, and criteria.

In addition, beginning in 1976, a series of reports were issued by the General Accounting Office, the Joint Committee on Atomic Energy, and the House Committee on Government Operations (Refs. 11, 12, 13, 14, and 15). The conclusions of these reports were wide ranging, but among the most basic was the conclusion that the existing sites had been selected and licensed on an inadequate geologic and hydrologic data base and in the absence of well-documented criteria for identification of a suitable waste disposal site. As a result, a number of the existing sites were experiencing undesirable operational problems, i.e., cracking of trench covers, intrusion of precipitation and ground water, and subsequent releases of radioactivity to the environment. Moreover, in the absence of an improved data base on site characteristics and development of defensible standards and criteria for licensing, the reports noted that the selection of future waste disposal sites might well encounter the same types of problems.

In response to the Task Force and Congressional reports and identified need, the NRC staff subsequently developed a program plan for low-level waste management. Support for the development of such a program came not only from the Task Force and the aforementioned reports, but also from state and other federal agencies, industry, and public interest organizations. To formulate this program, the staff considered the Task Force recommendations; public comments on the Task Force Report; data gleaned from review of technical documents and participation in conferences and meetings, and discussions attended by industrial, state, and public organizations; and other correspondence and documents. A document describing the program entitled "NRC Low-Level Radioactive Waste Management Program" (NUREG-0240) was published in September 1977 (Ref. 16). This program is currently in progress and has resulted in technical studies to prepare a regulatory base; programs for development of regulations, regulatory guides, and licensing procedures; and this environmental impact statement.

1.2.5 Description of the Proposed Action

The proposed action being considered in this EIS is the issuance of a new regulation (Part 61) to the U.S. Nuclear Regulatory Commission (NRC) rules in Title 10, Code of Federal Regulations. Part 61 will provide licensing procedures, performance objectives, and technical requirements for the issuance of licenses for the land disposal of low-level radioactive waste. Specifically, the proposed action includes consideration of requirements on the standards of performance that should be met in LLW disposal; technical requirements for the siting, design, operation, closure and postoperational activities for a near-surface LLW disposal facility; technical requirements on waste form that waste generators would be required to meet for acceptance of waste at a disposal facility; classification of waste; administrative and procedural requirements for licensing a disposal facility; and provisions for adequate financial assurance.

1.3 SCOPING FOR THIS EIS

Scoping of an environmental impact statement is defined by the Council on Environmental Quality in 40 CFR Part 501.7 (Ref. 2) as "...an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action." Although the concept of scoping is a relatively recent development for EISs, NRC has been conducting scoping activities relative to the proposed Part 61 and this EIS since 1978. The activities constituting this process are discussed in the following paragraphs and include:

1. Public Notice of Development of a Radioactive Waste Disposal Classification System (Ref. 17)

2. Advance Notice of Proposed Rulemaking on the LLW Disposal Regulation (10 CFR Part 61) (Ref. 18)

3. Public Review and Comment on a Preliminary Draft of 10 CFR Part 61 (Ref. 19)

4. Regional Workshops on 10 CFR Part 61 (Refs. 20, 21, 22 and 23)

In 1974, the Atomic Energy Commission (AEC) proposed to prohibit the disposal of commercially generated transuranic (TRU) radionuclides by shallow land burial. Upon review of the proposed rule and the comments received from interested parties, the NRC staff initiated development of regulations which would govern the classification of all radioactive wastes--not just TRU-contaminated waste.

The staff initiated a study to develop an approach for classification of waste to help provide input into the regulations development effort and environmental impact statement. Several documents have been published regarding this study. On August 18, 1978, NRC published a Federal Register notice of "Development of a Radioactive Waste Disposal Classification System" (43 FR 36722). In this notice, the Commission requested comments on a study report entitled "A System for Classifying Radioactive Waste Disposal--What Waste Goes Where?" (NUREG-0456) to guide the further development of a waste classification methodology and the completion of the study. Comments were specifically requested in the following areas: the overall approach; the migration pathways and exposure mechanisms; the exposure guidelines; and applications of the methodology.

A summary of the comments received by the Commission is contained in Appendix C including an analysis of the comments as they relate to the development of Part 61.

On October 25, 1978, NRC published in the Federal Register an Advance Notice of Proposed Rulemaking (43 FR 49811) regarding the development of specific regulations for the disposal of LLW; a new Part 61 to Title 10, Code of Federal Regulations. The Commission requested advice, recommendations, and comments on the scope and content of the regulations and an environmental impact statement (EIS) that would be prepared to guide and support development of the regulations. As a part of this Notice, NRC announced its intention to:

- Develop technical requirements for the disposal of LLW by shallow land burial and alternative disposal methods;

- Prepare a supporting EIS for the regulation; and

- Coordinate development of technical requirements for shallow land burial and alternative disposal methods with requirements for the classification of waste.

Formal comments received in response to the Advance Notice were placed in the Public Document Room of the NRC as an official part of the record for this Part 61 rulemaking proceeding (Docket No. PR61). Details of the comments received are contained in Appendix C, including an analysis of comments received on each specific question of the Advance Notice.

In general, the respondents to the Advance Notice strongly supported NRC's development of specific requirements for the disposal of low-level waste. There was also support among the commenters that an overall EIS should be prepared to provide an essential part of the information and decisional base for the development of the requirements for the rulemaking action.

In addition to the comments received by NRC on the Advance Notice, NRC staff also considered input from the following other sources in scoping the content of this EIS.

- The results of program studies and other technical data on LLW management and disposal;
- Licensing experience and current LLW management techniques at existing disposal sites;
- Input from the State Planning Council, National Governors Association, National Council of State Legislatures and National Conference of State Radiation Control Program Directors;
- Programs of the Environmental Protection Agency (EPA) to develop criteria and standards for management of LLW and regulations for disposal of nonradioactive solid and chemically hazardous wastes;
- Recommendations of the Interagency Review Group on Nuclear Waste Management;
- A Natural Resources Defense Council (NRDC) Petition for Rulemaking;
- Discussions with industry and public interest groups, state and federal agencies, and others.

To help focus development of the EIS and possible contents of such a new regulation, NRC staff also prepared and widely distributed for public review and comment a preliminary draft Part 61 regulation dated November 5, 1979. The preliminary draft received wide distribution and copies were sent to the states, other federal agencies, public interest groups, the industry, and others. On February 28, 1980, NRC staff also published in the Federal Register a Notice of Availability of the Preliminary Draft Regulation (Ref. 24) announcing availability of the draft for public review and comment to help ensure wide distribution and early public review, comment, and input.

Comments received by the staff in response to the Notice of Availability have also been docketed and placed in the Commission's Public Document Room. Overall, the comments generally agreed with the need for, and approach and general content of, the preliminary draft regulation. A summary of the comments received by the Commission is contained in Appendix C, including an analysis of comments received on each section of the preliminary draft of Part 61. A detailed listing of comments on specific sections of the preliminary draft of Part 61, prepared by the staff has also been placed in the Public Document Room, PR 61 Docket File.

During the summer and fall of 1980, NRC also contracted for and held 4 regional workshops to provide an opportunity for open dialogue between the states, public interest groups, industry, and others on the issues that needed to be addressed through the Part 61 rulemaking process. One workshop was sponsored by the Southern States Energy Board for the southeast region, a second by the Western Interstate Energy Board for the west, a third by the Midwestern Regional Office of the Council of State Governments for the central and midwest, and a fourth by the New England Regional Commission for the northeast. A copy of the full transcript for each meeting and a summary report documenting the collective views of the participants has been entered into the docket for this rulemaking and may also be examined at the Commission's Public Document Room. At these workshops, a range of institutional, organizational, and technical issues were discussed. Institutional issues such as land ownership, post-operational care, institutional controls, and financing were addressed. Consideration was also given to organizational issues such as state participation in NRC licensing action, Federal-Agreement relations, assistance to non-Agreement States, and regional siting. Technical issues that were examined included: performance objectives; de minimis levels; waste classification; nonradiological hazards; scope of regulatory guides and regulation; criteria for waste form; solidification of liquid wastes; volume reduction; and site characterization. In general, the workshops recommended that NRC adopt formal rules that establish broad performance objectives and administrative procedures, and set forth more specific program criteria and details in regulatory guides. A summary of the workshop findings and analysis of the findings on each specific issue considered is contained in Appendix C.

1.4 ISSUES ADDRESSED IN THIS EIS

Based on the results of NRC's scoping activities and the operating experience of the existing sites, the following issues were identified as those that were germane to this rulemaking action and of most importance in preparing this EIS:

1. The specific form and content of the requirements to be established and method to be applied in their development.

2. The alternative disposal methods which should be addressed in the rulemaking action.

3. The need to protect the public health and safety and environment during the short-term operational phase and over the long term relating to potential long-term releases to the environment.

4. The need to protect the inadvertent intruder.

5. The classification or definition of LLW based on hazard potential.

6. The need for adequate financial assurances in the disposal of LLW.

7. The need for long-term stability and predictability in disposal sites.

8. The need to eliminate long-term maintenance of disposal sites.

9. The NRC licensing process for waste disposal sites and the participation of the states, public and indian tribes in NRC's licensing process.

10. Long-term government land ownership and institutional control of disposal sites.

REFERENCES

1. National Environmental Policy Act of 1969, as amended, Public Law 91-190 as amended by Public Law 94-83.

2. Council on Environmental Quality, 40 CFR Parts 1500-1508, National Environmental Policy Act-Regulations, Federal Register, (43 FR 55978-56007), November 29, 1978.

3. U.S. Nuclear Regulatory Commission, 10 CFR Part 51, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions and Related Conforming Amendments, Federal Register, (43 FR.13739 - 13766), March 3, 1980.

4. U.S. Nuclear Regulatory Commission, NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds, NUREG-0217, March 1977.

5. Kentucky Department for Human Resources, Project Report of Six Month Study of Radiation Concentrations and Transport Mechanisms at the Maxey Flats Area of Fleming County, Kentucky, December 1974.

6. Matuszek, J. M., F. V. Strnisa, L. F. Baxter, Radionuclide Dynamics and Health Implications for the New York Nuclear Service Center's Radioactive Waste Burial Site, IAEA SM 207/59, March 1976.

7. U.S. Nuclear Regulatory Commission, Report to Congress on Abnormal Occurrences, NUREG-0090-3, January-March 1976.

8. U.S.Nuclear Regulatory Commission, Testimony on Low-Level Radioactive Waste Disposal Before the Subcommittee on Energy Research and Production, House Committee on Science and Technology, presented by Joseph Hendrie, Chairman, U.S. Nuclear Regulatory Commission, November 7, 1979.

9. South Carolina Department of Health and Environmental Control, Radioactive Material License No. 097, October 30, 1979.

10. U.S. District Court, Eastern District of Washington, Memorandum Decision for Case Number C-91-154 RJM and C-81-190 RJM by Robert J. McNichols, U.S. District Judge, June 26, 1981.

11. Comptroller General of the United States, Improvements Needed in the Land Disposal of Radioactive Waste - A Problem of Countries, January 12, 1976.

12. Comptroller General of the United States, Need For Greater Regulatory Oversight of Commercial Low-Level Radioactive, Waste, August 16, 1978.

13. Comptroller General of the United States, The Problem of Disposing of Nuclear Low Waste: Where Do We Go From Here, March 31, 1980.

14. Joint Committee on Atomic Energy, Radioactive Waste Management Hearing before the Subcommittee on Environment and Safety, May 10-12, 1976.

15. House Committee on Government Operations, Low-Level Nuclear Waste Disposal, House Report 94-1320, June 30, 1976.

16. U.S. Nuclear Regulatory Commission, The Nuclear Regulatory Commission Low Level Radioactive Waste Management Program, NUREG-0240, September 1977.

17. U.S. Nuclear Regulatory Commission, Development of a Radioactive Waste Disposal Classification System, Federal Register, (43 FR 36722-36725), August 18, 1978.

18. U.S. Nuclear Regulatory Commission, 10 CFR Part 61, Management and Disposal of Low-Level Wastes by Shallow Land Burial and Alternative Disposal Methods, Advance Notice of Proposed Rulemaking, Federal Register, 43 FR 49811-49812, October 25, 1978.

19. U.S. Nuclear Regulatory Commission, 10 CFR Part 61: Disposal of Low-Level Radioactive Waste and Low-Activity Bulk Solid Waste, Preliminary Draft, November 5, 1979.

20. Southern States Energy Board, Findings on NRC's Low-Level Rule Resulting from the Southern States Energy Board Workshop, May 15, 1980.

21. Western Interstate Energy Board, Report to the Nuclear Regulatory Commission, Workshop on Low-Level Waste Licensing Rule, July 25, 1980.

22. Midwestern Office, Council of State Governments, Report to the Nuclear Regulatory Commission, Workshop on Low-Level Waste Licensing Rule, August 28, 1980.

23. New England Regional Commission, Report to the U.S. Nuclear Regulatory Commission Summarizing the Proceedings of the November 6-7, 1980 Workshop on Low-Level Waste Management Licensing Rule.

24. U.S. Nuclear Regulatory Commission, 10 CFR Part 61, Disposal of Low-Level Radioactive Waste; Availability of Preliminary Draft Regulation, Federal Register, (45 FR 13104-13106), February 29, 1980.

Chapter 2

DEVELOPMENT OF REGULATIONS FOR LLW DISPOSAL

2.1 INTRODUCTION AND SUMMARY

This chapter reviews and resolves three key issues involved in developing a new Part 61 regulation. The resolution of these issues provides the basis upon which the technical and other requirements are developed. These issues are:

1. The type of requirements which should be developed and set out in Part 61 (i.e., performance objective or prescriptive requirements). The preferred alternative approach being followed by NRC in preparing these regulations is to develop both overall performance objectives that define acceptable safety standards that should be achieved in the disposal of LLW, as well as minimum technical requirements to control several key parameters important to assuring that the performance objectives will be met. Prescriptive requirements are established where possible;

2. The alternative methods of disposal which should be addressed in this rulemaking action. Based on an analysis of alternative disposal methods, NRC plans to address not only shallow land burial but also the full range of land disposal technology that can be applied near the earth's surface including shallow land burial, deeper burial and engineered designs; and

3. The methodology and approach that should be used to classify LLW and to direct particular types and forms of waste to disposal methods which ensure their safe disposal. Based on an analysis of alternative methods for classifying radioactive waste, NRC has further developed and applied the methodology previously described in two NRC documents (NUREG-0456 (Ref. 1) and NUREG/CR-1005 (Ref. 2)) to classify radioactive waste based on the requirements for its safe disposal.

2.2 PERFORMANCE OBJECTIVES VS PRESCRIPTIVE REQUIREMENTS

In developing specific regulations for LLW disposal, two basic types of requirements can be established: performance objectives and prescriptive requirements.

A performance objective regulation would establish the overall objectives that should be achieved in the disposal of LLW and leave flexibility in how the objectives would be achieved. The performance objectives would establish general technical requirements on the design and operation of an LLW disposal facility and would include a standard or standards to specify the level of radiological hazard which should not be exceeded at an LLW disposal facility.

A prescriptive regulation would set out specific detailed requirements for the design and operation of an LLW disposal facility. Prescriptive standards would specify the particular practices, designs, or methods which are to be employed--for example, the thickness of the cover material over a shallow land burial disposal trench, or the maximum slope of the trench walls. NRC considered three alternatives regarding the type of requirements which should be considered in Part 61:

1. Development of performance objective requirements only;

2. Development of prescriptive requirements only; and

3. Development of both performance objective and prescriptive requirements.

2.2.1 Performance Objective

Performance objective requirements, by their nature in establishing overall objectives, would allow maximum flexibility in the application of new technology and innovative solutions to assuring safety in the disposal of LLW. They would allow for a systems' type approach in that the performance of the "disposal system" would be based on the combined interaction and effectiveness of the many factors or component parts of a disposal system. Positive and negative characteristics can be balanced such that the performance of all characteristics in combination can be considered rather than just the characteristics of one element. This would allow for consideration of site-specific conditions and variation in the design, operation and characteristics of waste on a site specific basis.

Performance objective requirements, however, require more effort and time in development as well as in licensing of specific facilities due to the large number of factors that must be considered to determine compliance. In addition, it may not be totally clear to an applicant or interested person how to design and operate a disposal facility to meet the general objectives.

2.2.2 Prescriptive Requirements

This approach would prescribe the specific methods, designs and practices which should be applied in disposal. It requires a thorough understanding of all the potential methods, designs and practices that can be applied in the disposal of LLW. It also assumes that the state of the art in disposal technology is developed to the point where there are clear choices to be made among all the potential alternatives that could be used. It would be easy for an applicant or licensee to demonstrate compliance with prescriptive requirements (and for NRC to license and inspect against them) since engineering limits are established which can be readily measured or calculated and the specific requirements for the design and operation of a LLW disposal facility would be clearly defined and readily apparent to an applicant or licensee.

Prescriptive requirements would, however, tend to discourage use of new or creative solutions to waste disposal problems even though they might result in lower environmental impacts and monetary costs. Prescriptive requirements are difficult to derive and would need to frequently revised as the type and form of waste changed and as technology advanced. Prescriptive requirements would also tend to concentrate on the individual components of a disposal system and would tend to treat all wastes uniformly regardless of hazard potential.

2.2.3 Performance Objective and Prescriptive Requirements

This approach would involve the establishment of overall objectives to define a level of safety for LLW disposal and subsequent development of specific technical requirements to assure that the overall performance objectives are met. This approach would allow for:

1. Increased flexibility in determining the disposal requirements of particular waste streams;

2. Increased flexibility in accounting for site-specific environmental conditions;

3. Increased ability to incorporate improvements in technology for LLW forms, packaging and disposal;

4. Specification of minimum technical and prescriptive requirements based on current understanding and known problems of the past; and

5. More rapid future development of technical requirements for alternative disposal methods.

Finally, this approach allows for consideration of the individual components of an LLW disposal system and their contribution toward achievement of the overall performance objectives as well as consideration of the combined effectiveness of these components as a system.

2.2.4 Comparative Analysis

NRC believes that development of a regulation using solely prescriptive requirements or solely performance objectives would not prove effective for the future regulation of LLW disposal. Given the wide variation in the form and characteristics of waste that has and will continue to be generated; given the wide range in potential site characteristics in various regions of the U.S.; and given the fact that technological innovation in waste disposal problems is now receiving greater emphasis in finding improved solutions to LLW disposal problems, requirements of both types are needed. Minimum performance objective standards are necessary to define the overall performance expected in LLW disposal, whereas specific minimum technical requirements are necessary to avoid recognized undesirable characteristics based on past experience and current understanding. The alternative of establishing purely prescriptive requirements could result in a collection of *ad hoc* requirements without a clear picture as to the overall effectiveness of such requirements. This could lead to a situation not greatly different from the current situation. Development of purely performance objective requirements, while workable, would not allow for establishment of more detailed prescriptive requirements in those areas where specific guidance is known to be needed.

In this rulemaking effort, NRC thus plans to establish overall performance objectives or standards of performance that should be achieved in the disposal of LLW, minimum technical performance requirements that should be considered in all cases in the disposal of LLW and where possible, detailed prescriptive requirements. Subsequent to this rulemaking, NRC plans to publish regulatory guides in the areas of waste form, site suitability and design and operations which will provide detailed prescriptive guidance.

2.3 ALTERNATIVE DISPOSAL METHODS

As a part of its LLW program leading to development of this EIS and LLW regulation, (Ref. 3) NRC conducted a study of alternative LLW disposal methods to help ensure that all viable disposal methods were considered and that the initial issuance of the regulation and subsequent amendments would be directed at and based on the methods of disposal that would most likely be used. The first part of this study consisted of an investigation and screening of possible alternative disposal methods and selection of those that appeared most viable and which should be evaluated further. To help assure completeness of the initial listing and adequacy of the selection of viable alternatives, a panel of technically competent individuals of recognized waste management expertise was consulted for review and guidance. The results of this effort were published as NUREG/CR-0308 "Screening of Alternative Disposal Methods for the Disposal of Low-Level Radioactive Waste" (Ref. 4). The second part of the study involved a further evaluation of those alternatives selected as being most viable. The analysis was generic in nature and considered technical, political and economic factors in the analysis. The results of the analysis were published as NUREG/CR-0680 "Evaluation of Alternative Methods for the Disposal of Low-Level Radioactive Wastes" (Ref. 5).

On the basis of this analysis, five disposal alternatives were identified as most promising. These included:

1. Shallow land burial;
2. Deeper "intermediate" depth burial;
3. Mined cavity disposal;
4. Engineered structures; and
5. Ocean disposal (ocean dumping and sea-bed disposal with projectiles).

The study also concluded, that although further specific detailed analysis of individual disposal methods was needed, the results did not indicate any compelling health, safety or environmental reason to abandon existing disposal methods (e.g., shallow land burial) in place of an entirely new method of disposal such as mined cavity disposal. The disposal of radioactive waste in outer space was considered to be not developed to the point of technical and economically feasible use.

In considering the development of regulations for LLW disposal, NRC was thus faced with two basic categories of alternatives: Ocean disposal (including ocean dumping and sea-bed projectiles) and land disposal (involving both near surface and deep disposal techniques).

Although ocean disposal had been used by the U.S. previously and is currently being used by the Europeans, the U.S. has not practiced ocean disposal since 1970. There is some current interest in resuming ocean disposal operations. Under the Marine Protection, Research and Sanctuaries Act of 1972, the Environmental Protection Agency has responsibility and a program underway leading to development of criteria and procedures for issuing permits for sea disposal of LLW. In addition, disposal requirements for ocean and land disposal may be sufficiently different that they should be developed separately. Public comments in response to the advance notice of proposed rulemaking also expressed concern regarding the ocean disposal of LLW. NRC has, therefore, concentrated its regulations development efforts on land disposal methods.

As noted earlier, land disposal methods logically divide into two subcategories: those that take place near the earth's surface and those that involve very deep disposal. Near surface disposal encompasses the full range in technology that can be applied in LLW disposal near the earth's surface: i.e., shallow land burial, deeper burial (depths of 15-20 meters) and the use of engineered designs, barriers and other concepts. This EIS and initial regulations development effort concentrates on land disposal requirements and specific requirements that should be applied to assure safety in the disposal of LLW by near-surface disposal technology. It is in wide use today and there is no compelling health and safety reason to abandon near-surface disposal technology in place of something different. Specific requirements for methods of very deep disposal such as deep mined cavities are not considered in this EIS, but will be addressed by NRC in a subsequent rulemaking effort. In addition, there are other specific types of disposal methods such as hydrofracture and deep well injection that have been successfully used. These methods are not being specifically addressed in this EIS since they will only work well for a very narrow range of waste types and require specific hydrogeological media characteristics. They will be dealt with at a later time.

2.4 RADIOACTIVE WASTE DISPOSAL CLASSIFICATION

In recognition of the wide range of potential hazards that may exist with different types and forms of LLW, NRC undertook a study to determine how various types and forms of LLW should be defined, classified or controlled for purposes of waste disposal. As early as 1974, the AEC had proposed to prohibit the burial of transuranic (TRU) contaminated commercial waste (Ref. 6). In the proposed rule, a measurement sensitivity limit of 10 nanocuries TRU waste per gram of material was proposed. Material exceeding the concentration limit, would have been consigned to retrievable storage facilities operated by the federal government pending the development of a facility for the ultimate disposition of the waste. Several problems, however, in implementation of the rule were identified by persons commenting on the proposed rule, and the rule was never adopted by the AEC for commercial waste.

At the same time, the staff recognized that there were other nuclides and waste types that should be controlled in disposal, as well as TRU contaminated waste, and initiated a waste classification study to define the concentrations of individual nuclides and disposal requirements that should be applied to assure their safe disposal. The study has divided into three major parts. The first part involved examination of alternatives for classifying LLW and selection of a preferred approach. This part is described in the report "Determination of a Radioactive Waste Classification System," UCRL-52535 (Ref. 7). The second part involved development and application of a methodology to classify wastes following the preferred approach selected. This part is described in two reports, "A Classification System for Radioactive Waste Disposal--What Waste Goes Where?," NUREG-0456 (Ref. 1) and "A Radioactive Waste Disposal Classification System," NUREG/CR-1005 (Ref. 2). The third part of the study was carried out as a part of this EIS and involves development of a waste disposal classification regulation and, a decision basis for the final classification values.

2.4.1 Alternative Classification Systems Examined

There are two dominant aspects of LLW disposal that must be considered in the development and application of any waste classification system: the characteristics and properties of LLW and the performance capability presented by alternative disposal methods and variations within each method. The characteristics of LLW present wide ranges in degrees of radiological, chemical, biological and physical hazards as well as in degrees of persistence of the hazards. Individual disposal techniques also present varying degrees of containment and isolation capability. Near surface techniques, for example, place the waste in an area that is readily accessible to man, while others, such as deep mines, present greater difficulties in accessibility.

Other considerations that needed to be addressed in the classification of LLW included:

1. Any classification system developed must be applicable to all sources of waste and must provide a common basis for application by those generating the waste as well as those disposing of the waste.

2. It must provide a sound basis for determining the controls (or requirements) that must be placed on the disposal of the waste to assure protection of the public health and safety and environment and minimize the need for long-term social commitment.

3. The system should be practical and implementable without placing undue burdens on those directly affected by it.

NRC initially examined a number of existing classification systems for radioactive waste to see if any could be utilized and applied. As a part of this effort, assistance was also sought from representatives of industry, government, the public, and research and educational institutions through a technical advisory panel. The panel assisted in evaluating existing classification systems and in providing guidance to NRC in the selection of an approach which NRC could apply in classifying LLW. Some of the systems examined included existing classification systems such as:

- o The International Atomic Energy Agency Radioactive Waste Categories;
- o The American Institute of Chemical Engineers Radioactive Waste Categories;
- o The American National Standards Institute Radioactive Waste Categories; and
- o The Atomic Energy Commission Radioactive Waste Management Classifications.

Members of the Technical Advisory Panel also proposed five additional classification systems to provide further guidance and alternatives for consideration. These five systems and the existing systems considered are described in detail in the report "Determination of a Radioactive Waste Classification System," UCRL-52535 (Ref. 7).

2.4.2 Preferred System Selected

Based on this study, the existing classification systems generally fell into three categories: those based on the source or generator of the waste (e.g., reactor wastes, medical wastes, industrial wastes); those based on the characteristics of the waste (e.g., solid, liquid, gas) and those based on the method of disposal (e.g., shallow land burial, ocean dumping, deep geological repository).

Classification of waste based on the "source of waste" was not considered useful since it would reveal little about the characteristics of waste and the requirements needed for its safe disposal. Likewise the characteristics and properties of the waste needed to be considered in developing a classification system but not to the exclusion of the method to be used for disposal.

It was concluded, therefore, that the preferred approach should be to develop a classification system based on the method or requirements that should be applied for disposal. The requirements for disposal could then be defined by the waste characteristics, the containment and isolation capabilities of the method of disposal and the social commitment controls required to assure safe disposal of the waste.

A methodology to classify waste based on this preferred alternative was subsequently developed and is reported in detail in NUREGs-0456 and 1005 (Refs. 1 and 2). The methodology developed involved identifying a set of exposure events at model waste disposal facilities, describing potential radionuclide transport to man, and then calculating limiting concentrations or inventories of radionuclides in waste that may be placed in the model disposal sites to ensure that specified dose guidelines would not be exceeded. The set of potential exposure events that was considered in the analysis included events in which individuals may come in contact with the waste (e.g., inhalation of dust by an intruder digging in the waste at a future point in time) and events in which the waste radioactivity was transported offsite by water or air (e.g., groundwater migration to a water resource pathway). Preliminary activity concentrations or inventories of material were calculated that would assure that the doses to any potentially exposed individual or total population would not exceed proposed acceptable dose guidelines assumed for purposes of the study. This is the approach that NRC has followed in developing a classification system for LLW. The details are presented in Chapter 7.

2.4.3 Other Issues Regarding Classification

Two final issues remain regarding classification. One involves classifying radioactive waste on the basis of total hazard. The second involves establishment of a de minimis classification of wastes. Each is discussed below.

2.4.3.1 Classification by Total Hazard

Given the wide range in potential hazards presented by LLW (e.g., chemical, biological, physical as well as radiological), NRC also initiated a study to examine chemical and other hazards associated with LLW and to examine if a quantitative method could be developed and applied for comparing radiological hazards with chemical hazards (Ref. 8). Also, recently the draft document "Managing Low-Level Radioactive Wastes: A Proposed Approach" (Ref. 9) suggests that a classification system should be developed based on total hazard-chemical, biological and physical as well as radiological. Based on the study results and current technical abilities to characterize potential effects of biologically and chemically hazardous wastes and to make direct comparisons with potential radiological hazards, it is not technically feasible at this time to break down all the different hazards and to assign a hazard factor that represents some weighted index of hazard.

Thus, NRC does not plan to address classification of waste by total hazard as part of its classification of LLW. Disposal requirements will be determined based principally on radiotoxicity. NRC plans, however, through specific requirements on waste form and content, to address associated potential chemical, biological and physical hazards. In general, the site and other requirements being developed for radioactive waste should be adequate to cover other hazards.

In some cases NRC is also taking specific action to eliminate or minimize potential chemical and biological hazards. A good example of this relates to the emphasis NRC has placed on the incineration of liquid scintillation fluids to destroy the organic solvents rather than continuing to utilize land disposal (Ref. 10).

Finally, as EPA develops its program of regulation for chemically hazardous waste, NRC will review EPA requirements for application at LLW disposal sites. The methodology and approach NRC is developing for classifying waste is sufficiently flexible that it should be able to accommodate any classification system EPA may develop for hazardous waste.

2.4.3.2 De Minimis

NRC recognizes the need for a "de minimis" classification of wastes that would be exempt from Part 61 and would be considered of no regulatory concern. NRC believes, however, as has been recommended by the Federal Radiation Policy Council (Ref. 11), and supported by public comments in the scoping process that such exemptions should be determined on a specific waste stream basis. In this regard, a final rule was recently published that establishes such an exemption in a new §20.306 for tritium and carbon-14 not exceeding a concentration of 0.05 μCi/gm when contained in liquid scintillation cocktail and animal carcass waste (Ref. 12). Other waste streams may also readily lend themselves to treatment in this manner. Finally, as a part of each specific licensee's program, authorization can be obtained to store very short half-life radionuclides for decay (generally for 10 half-lives) and to dispose of such waste as nonradioactive waste according to the other properties of the waste. Thus, through this EIS, NRC does not plan to establish a generic "de minimis" category for waste.

REFERENCES

1. Adam, J. A., V. C. Rogers, A Classification System For Radioactive Waste Disposal-What Waste Goes Where?, NUREG-0456, June 1978.

2. Rogers, V.C., A Radioactive Waste Disposal Classification System, Volumes 1 and 2, NUREG/CR-1005, prepared for U.S. Nuclear Regulatory Commission by Ford, Bacon and Davis Utah Inc., September 1979.

3. U.S. Nuclear Regulatory Commission, The Nuclear Regulatory Commission Low-Level Radioactive Waste Management Program, NUREG-0240 September 1977.

4. Macbeth, P. J., et al., Screening of Alternative Methods For the Disposal of Low-Level Radioactive Waste NUREG/CR-0308, prepared for NRC by Ford, Bacon and Davis Utah, Inc., October 1978.

5. Macbeth, P. J., et al., Evaluation of Alternative Methods for the Disposal of Low-Level Radioactive Waste, NUREG/CR-0680, prepared for NRC by Ford, Bacon and Davis Utah, Inc., July 1979.

6. U.S. Atomic Energy Commission, 10 CFR Part 20, Transuranic Waste Disposal, Proposed Standards for Protection Against Radiation, Federal Register, 39 FR 32921, September 12, 1974.

7. Cohen, J. J., W. C. King, Determination of a Radioactive Waste Classification System, Lawrence Livermore Laboratory, University of California UCRL-52535, March 1978.

8. General Research Corporation, Study of Chemical Toxicity of Low-Level Wastes, prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-1793, Volumes 1 and 2, November 1980.

9. EG&G Idaho, Inc., Managing Low-Level Radioactive Wastes, A Proposed Approach, Low-Level Waste Strategy Task Force, LLWMP-1, August 1980.

10. Roche-Farmer, L., Study of Alternative Methods for the Management of Liquid Scintillation Counting Wastes, NUREG-0656, U.S. Nuclear Regulatory Commission, February 1980.

11. U.S. Radiation Policy Council, Progress Report and Preliminary 1981-83 Agenda, RPC-80-001, September 1980.

12. U.S. Nuclear Regulatory Commission, 10 CFR Part 20, Biomedical Waste Disposal, Federal Register, 46 FR 16230, March 11, 1981.

Chapter 3

DESCRIPTION OF THE AFFECTED ENVIRONMENT AND APPROACH FOLLOWED IN PREPARING THIS EIS

3.1 INTRODUCTION

The environment affected or potentially affected by the generation, transport and disposal of LLW encompasses the whole of society. It consists of all the industries, hospitals, private individuals, government agencies and laboratories that generate LLW through the use of radioactive materials as a normal part of their day-to-day activities and functions. It consists of those involved in providing services such as supplying packaging and waste processing services at waste generator facilities and transporting waste from waste generator to disposal facilities. It consists of those involved in the ownership, operation and long-term control of the disposal facilities and the various regulatory agencies such as NRC, DOT and the state radiation control programs that license, regulate and inspect all phases to assure an adequate level of safety. It consists of society; the individuals, small population groups (e.g., radiation workers) and the general population that can be potentially affected by the various activities involved in the generation and disposal of waste. Finally, it consists of the natural environment including the ground and surface water, the atmosphere and various plant and animal species that would be affected by site-specific activities.

The affected environment for a rulemaking is, by nature, quite differently divided into direct and indirect segments than the affected environment described for a specific facility that might be proposed to be licensed. In the case of a rulemaking proceeding, the environment experiencing direct impacts are those parts which may have to change their way of carrying out specific activities or whose activities would be influenced if a new regulation were developed. Included would be the generators of waste, those providing services, the regulatory agencies, those owning and operating disposal sites, and society as a whole. The parts of the environment experiencing indirect impacts would be the natural environment with respect to the impacts on ground water, air, and plant and animal species due to application of the rule at a specific site.

In this EIS, NRC has concentrated on those segments of the environment that would experience the greatest impacts; those generating and disposing of the waste, society and the natural environment that would be affected by the costs, exposures and commitment of social and natural resources required to properly dispose of LLW. In analyzing the impacts of disposal, NRC divided the disposal process into three principal phases: (1) generation involving the processing of waste prior to disposal either at the point of generation or at a central location, (2) transportation of the waste from the point of generation to the disposal location, and (3) disposal of the waste.

In the following sections, the process NRC has followed in this EIS to characterize and analyze the affected environment involving the generation, transport, and disposal of waste and the impacts on each segment due to development of a new Part 61 rule is described. Section 3.2 reviews the approach NRC has followed in this EIS leading to development of performance objectives, technical and other requirements that are being codified through the Part 61 rulemaking action. Section 3.3 explains how NRC developed a base of data about LLW, methods of disposal and a calculational methodology to perform the required analyses. Section 3.4 deals with waste generation. It describes the waste generators and explains how NRC has organized a base of data about the sources and characteristics of waste to place it into a form and size that is manageable for purposes of this EIS. Section 3.5 deals with transportation. It describes the type of packaging and transport vehicles used, frequency of shipments, miles travelled, costs and other data. Section 3.6 deals with disposal. It describes the disposal of waste as it has been carried out through the characterization of a reference (base case) near-surface disposal facility. Analysis of the disposal of waste at the reference facility is performed in Chapters 4, 5, 6, and 7 and provides a base line level of the costs and impacts presented by the generation, transport, and disposal of waste. It represents the "no action" alternative. The incremental changes to these base line costs and impacts due to application of various alternatives which would be implemented because of new requirements in a new Part 61 regulation can then be evaluated leading to the selection of preferred requirements. Section 3.7 describes the various design and operations alternatives analyzed in the EIS. Section 3.8 describes the methodology developed to calculate various impact measures and the impact measures selected for use in this EIS to characterize the costs, benefits and radiological impacts of the generation, transport, and disposal of LLW. The impact measures, which include dose to members of the public, occupational exposures, costs, energy, and land use, are applied to evaluate the costs and benefits of the various alternatives analyzed in Chapters 4, 5, 6, and 7. The analyses in Chapters 4, 5, 6, and 7 provide the basis for decisions on the specific performance objectives and technical requirements that should be included in Part 61. After selection of the preferred requirements, Chapter 10 analyzes the typical unmitigated costs and impacts of application of the rule to various sectors of society and the environment.

3.2 APPROACH TO PREPARATION OF THIS EIS

The performance objectives and technical requirements for low-level waste disposal are being developed based on the results of the analyses presented in this EIS. The analyses are tiered from the generic to the specific. First, overall performance objectives are evaluated and preferred objectives are selected to define a level of safety and social commitment that should be achieved in the disposal of LLW. Second, technical requirements for the near-surface disposal of waste are evaluated based on the performance objectives and preferred requirements are selected. The performance objectives and technical requirements collectively establish a classification of waste for near-surface disposal in that they define the controls which should be applied in the near-surface disposal of waste (and which wastes are generally not acceptable for near-surface disposal). Administrative and procedural requirements for licensing the land disposal of LLW are evaluated and preferred requirements selected. The need for and provisions for adequate financial assurance for closure, postclosure care and institutional control are evaluated and preferred requirements selected. Finally, the unmitigated impacts of application of the preferred requirements are analyzed through evaluation of disposal of waste on a regional basis in accordance with the preferred requirements.

3.2.1 Need for Performance Objectives

NRC initially planned to develop only the technical requirements needed to assure safety and environmental protection in the disposal of LLW. These requirements would have been derived from a consideration of the currently established level of safety and environmental protection that should be achieved in LLW disposal. In evaluating the level of safety which should be achieved, NRC identified 3 components that needed to be considered:

1. Protection of occupationally exposed workers and the public during operation of the facility;

2. Long-term environmental protection; and

3. Protection of an inadvertent intruder.

A level of safety has been established for occupationally exposed workers and protection of the public during operation of the facility and is set out in the existing standards in 10 CFR Part 20 which applies to the activities of all NRC licensees. However, neither the federal government nor national and international organizations have defined such a level of safety specific to the disposal of LLW involving long-term environmental protection and protection of an inadvertent intruder. NRC thus had to also establish performance objectives to define the level of safety which should be achieved for each of these in disposal. With respect to standards on long-term releases to the environment, the Environmental Protection Agency is developing such standards through its overall program to develop generally applicable environmental standards; however, no standard for LLW disposal presently exists. Protection of an inadvertent intruder is a new concept, generally unique to disposal of waste. There are no existing standards for protection of an inadvertent intruder. In addition, there was a fourth component, generally unique to waste disposal that also needed to be addressed; long-term social commitment. Future generations should not be burdened with long-term expensive commitments to care for wastes generated today, and the development of requirements for the disposal of waste should take into account the long-term commitment of social and natural resources to care for waste over the long term. Thus, in addition to development of the technical requirements for how waste should be disposed of to meet an acceptable defined level of safety, NRC also had to develop and define such a level of safety for two areas--long-term environmental releases, and protection of an inadvertent intruder. (A level of safety for short-term operations has already been defined through 10 CFR Part 20.) NRC also had to consider the level or degree of social commitment that should be applied in the disposal of waste. These performance objectives would establish the level of safety and environmental protection that should not generally be exceeded in the disposal of LLW and the social commitment required in disposal.

3.2.2 Development of Performance Objectives, Technical and Other Requirements

The approach NRC has followed in the analyses of LLW disposal is to first analyze the generation and disposal of LLW as it has been carried out to see what the costs and impacts are. This analysis is termed the "base case" analysis and represents the "no action" alternative--i.e., no new requirements are developed and past practices continue. NRC next analyzes a range of modifications and improvements (alternatives to the base case) that could be applied with current technology and calculated the costs and impacts of such modifications and improvements. A range of alternative numerical performance objectives for intrusion and long-term environmental protection are also evaluated. These analyses are then utilized to select performance objectives for the intruder, environmental releases and social commitment. The preferred numerical objectives are selected based on a comparative evaluation of costs and benefits, are achievable today with existing technology and require some increased cost and effort. The objectives selected define an improved level of safety and environmental protection and reduced degree of long-term social commitment than that expected from past operations.

The analyses also identified three key aspects that are of most significance in ensuring long-term safety and environmental protection and in minimizing the degree of social commitment in the near-surface disposal of waste. These are: long-term stability of the disposal site; liquids in waste and the contact of water with waste both during operations and after closure; and institutional and other controls to reduce the likelihood of inadvertent intrusion. These three key aspects are then translated into technical requirements that must be applied in the near-surface disposal of waste. These requirements are applied to the four principal and readily identifiable components of a disposal system: site characteristics, site design and operations, waste form and packaging, and institutional control.

In analyzing past practices at the existing sites, only natural characteristics of the disposal site environment had been principally relied upon to provide confinement of the waste over the long term. The experiences at several of the existing sites have shown the need to consider several components collectively--a series of "multiple barriers"--rather than relying principally on just one component (i.e., the site).

This concept can be carried to an extreme such that each component of the system is designed so that it will guarantee success regardless of the performance of the other components. NRC has not followed this approach but has set levels of performance for each component, so that when considered individually, each will provide a degree of assurance and when considered collectively will provide a high level of assurance that the performance objectives will be met over the long term.

The following components collectively encompass the LLW disposal system and were specifically addressed in the development of technical criteria:

1. Site Characteristics - The geohydrological, geomorphological, climatological and other natural characteristics of the site on which the disposal facility is located.

2. Design and Operations - The methods by which the site is utilized, the disposal facility design, the methods of waste emplacement, and closure of the site.

3. Waste Form and Packaging - The characteristics of the waste and its packaging.

4. Institutional Controls - The actions, including assurance of adequate financial resources, which involve a government agency maintaining surveillance, monitoring, and control over access and utilization of the site after closure.

NRC next analyzed a range of specific alternatives that could be used in near-surface disposal to help ensure long-term stability, reduce water contact with waste, and reduce the potential for inadvertent intrusion. In some cases, based on the alternatives analysis and past known experience at the existing sites, a specific prescriptive requirement was selected and applied. For example, with respect to the use of active institutional controls to prevent inadvertent intrusion, NRC analyzed a range of alternative time periods for such controls (from 50-300 years) and selected 100 years as the preferred time upon which reliance should be placed on such controls. In a second case, placing certain higher activity wastes into a stable waste form, NRC evaluated a range of alternatives (including waste processing, use of containers and facility design) but selected no preferred alternative. In this case, each alternative presented an equivalent degree of long-term stability at a range of costs depending upon the particular type and volume of waste and the individual capabilities of the waste generator. No specific prescriptive requirement was selected to allow maximum flexibility in meeting the objective, to allow for individual preferences and capabilities and to allow for individual cost-benefit determinations. The performance objectives and technical requirements selected also collectively establish a definition or classification of waste for near-surface disposal in that they define the controls which should be applied in the disposal of waste at a near-surface disposal facility (and also define which wastes are generally not acceptable for near-surface disposal). NRC considered some alternatives for setting out the classification system and selected the alternative of establishing concentration limits for individual nuclides in wastes that generators and disposal site operators could readily apply in determining the classification of a particular waste and the particular controls that should be applied in the disposal of that waste.

As a part of the development of the minimum technical requirements, NRC also analyzed the need for financial assurance to cover the cost for closure and postclosure surveillance, monitoring and care. A range of alternatives was reviewed and requirements were developed from the preferred alternatives to ensure adequate financial assurance in the disposal of LLW. The results of the base case "no action" and alternatives analyses are set out in Chapters 4-6. The classification of waste for near-surface disposal is set out in Chapter 7. Financial assurance is addressed in Chapter 9.

Finally, as part of development of the technical requirements, NRC examined the existing administrative and procedural requirements that are applied by

NRC in the licensing of LLW disposal facilities including procedures for participation by states and others in the NRC licensing process. Alternatives for improvement were analyzed and preferred alternative changes to these procedural requirements were selected. The results of this analysis are set out in Chapter 8.

3.2.3 Codification of Requirements into a New Part 61 Rule

The performance objectives, technical and other requirements developed through the analyses presented in Chapters 4-9 collectively form the basis for the new requirements to be codified through the Part 61 rulemaking actions. The requirements developed seemed to fall into one of three categories: (1) requirements which were a codification of existing practice, (2) requirements which represented an improvement or deviation from existing practice, and (3) requirements which seemed to fall into both categories (1) (2)--e.g., a practice that may only currently be applied at one site. For those requirements which codified existing practice, no cost-benefit evaluation was carried out since they represent current state-of-the-art and are reflected in the base case analysis. For these, the cost of complying with the requirement was considered and included in the base case cost data and the impacts reflected in the impacts for the base case analysis. Requirements in Category 2 that represented improvements or modifications were subjected to cost-benefit evaluation in terms of the incremental cost increase over the base case and the resultant change (increase or decrease) in impacts resulting from application of the new requirement. For those in category (3), staff judgment was applied in placing the requirement into either category (1) or (2).

The results of the analyses presented in Chapters 4-9 indicate that with modest increases in cost relating to improving the form and properties of waste shipped for disposal and modest improvements in the design and operation of a near-surface disposal facility (many of which are being used at some of the existing sites today) the potential health, safety, and environmental impacts from disposal of LLW and the degree of long-term social commitment can be greatly reduced. The ability to predict the long-term performance and impacts of near-surface disposal facilities is also greatly improved and the uncertain and high costs required to care for disposal sites over the long term are reduced. Stated simply--we can put some modest increased effort and cost into the disposal of LLW today leading to reduction in potential impacts, reduction in long-term care costs and increased confidence in the performance capability of near-surface disposal facilities. Or, we can continue as we have in the past possibly leading to situations as has been evidenced at some existing sites where the potential impacts over the long term may be high, the costs for long-term care high, and confidence in the long-term performance low. The proper course of action is the former and the performance objectives, technical, and other procedural requirements selected are set out in a new Part 61 regulation and in amendments to existing parts of NRC's regulations.

3.2.4 Unmitigated Impacts of Implementing Part 61

Finally, as a part of this EIS, NRC has also conducted an analysis of the preferred requirements to be included in the new Part 61 rule to better judge their applicability to the wide range in site and waste characteristics expected through regional disposal of LLW and to better judge the overall impacts of implementation of the rule. This analysis involves application of the requirements at several regionally located sites where the waste generated within each region is shipped for disposal. Each of the disposal facilities is sited, designed, and operated in compliance with the preferred requirements accounting for regional differences and variations that might be expected. The results of this analysis are set out in Chapter 10.

3.3 DEVELOPMENT OF DATA BASES FOR THE ANALYSES

To perform the base case and alternatives analyses, NRC developed a base of information and data about the affected environment and LLW disposal--who generates the waste; how is it processed, packaged, and shipped for disposal; how is it disposed of today; and what kinds of modifications and improvements can be made to existing practices and at what cost. In addition, NRC developed a methodology to calculate the costs and impacts of various combinations of site features, waste characteristics, designs, operating procedures, closure and long-term care conditions.

The data was divided into 5 major portions as follows:

- o Information on the sources, characteristics, treatment and packaging of LLW. (Set out in Appendix D)
- o Information on the siting, design, operation, closure and long-term care of a reference LLW disposal facility. (Set out in Appendix E)
- o Information on possible technological improvements and variations that could be applied to near-surface disposal technology. (Set out in Appendix F)
- o Information on assuring adequate financial resources and arrangements for site operations, closure and long-term care. (Set out in Appendix K)
- o Information on administrative and procedural considerations that should be applied in licensing a near-surface disposal facility. (Set out in Chapter 8)

A description of the methodology developed to calculate the costs and impacts for disposal is set out in Appendices G and H.

The application and use of these data bases in this EIS and their interrelationship is described below including the major assumptions made and method of analysis used. Each is described in greater specific detail in the referenced appendices.

As noted earlier, the data has been developed and analyzed according to three major phases: generation of the waste (described in Section 3.4), transport of the waste (described in Section 3.5), and final disposal (described in Section 3.6).

3.4 WASTE GENERATION

This section describes the affected environment made up of those generating LLW. It includes the industries, hospitals, colleges, and others who generate LLW; the physical, chemical, radiological, and other characteristics of the wastes as it is generated; the volume of the waste as it is generated; changes in waste characteristics due to treatment or processing of the waste; the packaging used for transport and disposal; and the occupational exposures, population exposures, costs and energy used for processing, packaging and handling of the waste at the point of generation.

3.4.1 Waste Generators

LLW is generated by more than 20,000 NRC and Agreement State licensees throughout the country and by a number of government operations, particularly Department of Energy (DOE) facilities. While some DOE wastes were previously disposed of at commercial disposal facilities, all DOE wastes are now disposed of at DOE owned and operated facilities which are not subject to NRC or Agreement State licensing authority. Such wastes are thus not addressed in this EIS. The waste addressed in this EIS is generated by a wide variety of licensed programs including fuel cycle facilities such as nuclear power reactors, reactor fuel fabrication plants and uranium hexafluoride conversion plants. Other wastes are generated by a number of nonfuel cycle facilities including hospitals, medical research institutions, colleges and universities, industrial research labs, government labs, facilities involved in the production of radiopharmaceuticals, and other industrial uses of radioactive materials.

3.4.2 Description of the Waste as Generated

In general, the waste is very diverse in terms of volume, activity, and characteristics. It essentially includes everything that is discarded as waste and ranges from trash that is only suspected of being contaminated to highly radioactive activated structural components from nuclear power reactors. Currently about 85,000 m^3 (3 million ft^3) of commercial LLW is generated annually that ranges in activity from hundreds to thousands of curies per cubic meter to less than a few microcuries per cubic meter. Most of the activity disposed of at the commercial sites is contained in a relatively small volume of waste and is generated by less than 100 licensees. The form of the waste generated can be solid, liquid, or gaseous. It can consist of a wide range of chemical forms and can be shipped in a number of different types of packages. Based on projections of LLW volume prepared by NRC for the basic waste streams considered in this EIS, about 3.62 million m^3 (128 million ft^3) will be generated during the period 1980-2000. Of this, about 65% of the waste will be generated by fuel cycle sources and 35% by nonfuel cycle sources. Institutional generators will account for about 19% of the nonfuel cycle sources.

3.4.2.1 Fuel Cycle Facilities

The LLW produced by commercial nuclear power plants can be divided into six basic categories: ion exchange resins, concentrated liquids, filter sludges, compactible trash, noncompactible trash and nonfuel irradiated reactor components. Ion exchange resins are used in reactors to remove dissolved radioactivity from liquid streams. When spent, they are exchanged and the spent resins are placed into a shipping container (usually referred as a liner) where excess water is removed (dewatering) prior to transfer to a disposal site. In some cases the spent resins may be solidified with binders such as cement or urea-formaldehyde. Resin waste in shipping containers is usually transported in a cask or overpack that is shielded for radiation protection purposes. Concentrated liquid waste is produced by the evaporation of a wide variety of reactor liquid streams. These concentrated liquids are solidified in various materials such as cement, placed in a shipping container, and shipped to a disposal site. Filter sludge is waste produced by precoat filters and consists of powdered filter material. It is used to remove suspended and dissolved material from liquid streams. Filter sludge waste is generally dewatered and placed into a container for disposal. Compactible and noncompactible trash consists of everything from paper towels, plastic, and glassware to metallic components such as pipes and contaminated tools. Nonfuel irradiated components consist of fuel channels, control rods, and in-core instrumentation that has been exposed to in-core neutron flux.

Other nonfuel cycle waste streams include process waste and trash from uranium hexafluoride and fuel fabrication plants. This can include calcium fluoride generated in hydrogen fluoride gas scrubbers, filter sludges and paper, plastic, equipment and other trash. These are generally packaged in 55 gallon drums or larger containers and shipped for disposal.

3.4.2.2 Nonfuel Cycle Facilities

Institutional waste generators include colleges and universities, medical schools, medical research facilities, private physicians and hospitals. These institutions use radioactive materials in many diverse applications including analytical instruments, diagnosis and therapy, research and instruction. The type of waste generated generally falls into six groups: liquid scintillation vials, liquids, biological wastes, trash, accelerator targets and sealed sources. Liquid scintillation vials are generally made of glass and contain organic solvents and small amounts of radioactivity. They are ususally packaged in 55-gallon drums with absorbent material for disposal. Absorbed liquids consist of organic and aqueous liquids generated by various preparatory and analytical procedures involving radioactive material. They are absorbed on media such as diatomaceous earth and packaged in 55-gallon or smaller drums. Biological wastes consists of animal carcasses, tissues and culture media used in research programs. It is usually treated with lime and packaged in 55-gallon drums for disposal. Institutional trash consists mostly of paper, rubber, plastic, broken labware and disposable syringes. Sealed sources consist of radioactive material that has been encapsulated to contain and prevent leakage of the material. Sealed sources are packaged in a shielded container for transport and are sometimes disposed of in toner tubes or caissons backfilled with concrete.

Industrial waste generators include firms engaged in the production of radioisotopes for medical, research and industrial applications; industrial research and development activities; manufacturing and distribution of products containing radioactive material; and uses in quality control and manufacturing processes. The uses of radioactive materials and resulting wastes produced are diverse and can consist of: sealed sources, compactible and noncompactible trash, radioisotope production wastes, and a range of biological, scintillation and absorbed liquids similiar to those generated by medical and educational institutions.

3.4.3 Characterization of LLW for Purposes of Analysis

Given the large number of individual waste generators and diverse nature of the waste generated, coupled with changes that can be made in the form of the waste due to processing and the number of different types of packaging that can be used, an infinite number of variations are possible. All such variations cannot be analyzed. To characterize such a wide diversity in possible waste streams and to bound the variations that might be expected, NRC analyzed currently available information about the sources, form, content and characteristics of waste. The data base developed, based on this analysis, consists of a projection of the volume and physical, chemical, and radiological characteristics of waste to be routinely generated during the period 1980 to the year 2000.

3.4.3.1 Waste Stream Characterization

Based on the analysis NRC was able to group the major types of wastes generated into 36 individual waste streams. The 36 streams are summarized in Table 3.1. The streams characterize the wastes that are presently being routinely generated or are expected to be routinely generated in the future. The major waste generators analyzed included nuclear fuel cycle facilities such as nuclear power, fuel fabrication and uranium hexafluoride conversion plants, and nonnuclear fuel cycle sources such as hospitals, colleges, research labs, medical isotope production facilities, and industrial facilities. Each waste stream represents a particular type of waste generated by a particular type of waste generator having particular physical, chemical, radiological, and other characteristics unique to that individual stream. (For example, one stream is ion exchange resins, generated by boiling water reactors which contains concentrations of several specific radionuclides. This waste is usually packaged in a dewatered form in a steel liner for disposal.) NRC reviewed existing information and characterized in detail each of the 36 waste streams. The most important radionuclides present in the waste streams were identified and the geometric mean of the range of activity concentrations for each radionuclide observed was determined from available data. The radionuclides considered are shown in Table 3.2. For those streams where limited data was available, estimates were made based on scaling factors from the known composition of similar or related waste streams. Each stream was identified by a particular alphameric symbol for ease in identification during computer analysis (e.g., boiling water ion exchange resins are denoted by B-IXRESIN). The following symbols have been used to denote the major waste generators:

Symbol	Generator
P	Pressurized Water Reactors
B	Boiling Water Reactors

Table 3-1 Waste Streams Considered in Analyses

Waste Stream	Symbol
<u>Group I: LWR Process Wastes</u>	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartridges	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
<u>Group II: Trash</u>	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-NCTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS* Trash (large facilities)	N-SSTRASH
Industrial SS Trash (small facilities)	N+SSTRASH
Industrial Low Trash (large facilities)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
<u>Group III: Low Specific Activity Wastes</u>	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV** Waste (large facilities)	I-LIQSCVL
Institutional LSV** Waste (small facilities)	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS Waste	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
<u>Group IV: Special Wastes</u>	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
Industrial High Activity Waste	N-NIGHACT

*SS: Source and Special Nuclear Material
**LSV: Liquid Scintillation Vial

Table 3.2 Radionulides Considered in Analyses

Isotope	Half Life (years)	Radiation Emitted	Principal Means Of Production
H-3	12.3	β	Fission; Li-6 (n, α)
C-14	5730	β	N-14 (n, p)
Fe-55	2.60	γ	Fe-54 (n, γ)
Co-60	5.26	β, γ	Co-59 (n, γ)
Ni-59	80,000	γ	Ni-58 (n, γ)
Ni-63	92	β	Ni-62 (n, γ)
Sr-90	28.1	β	Fission
Nb-94	20,000	β, γ	Nb-93 (n, γ)
Tc-99	2.12×10^5	β	Fission; Mo-98 (n, γ), Mo-99 (β^-)
I-129	1.17×10^7	β, γ	Fission
Cs-135	3.0×10^6	β	Fission; daughter Xe-135
Cs-137	30.0	β, γ	Fission
U-235	7.1×10^8	α, γ	Natural
U-238	4.51×10^9	α, γ	Natural
Np-237	2.14×10^6	α, γ	U-238 (n, 2n), U-237 (β^-)
Pu-238	86.4	α, γ	Np-237 (n, γ), Np-238 (β^-); daughter Cm-242
Pu-239	24,400	α, γ	U-238 (n, γ), U-238 (β^-), Np-239 (β^-)
Pu-240	6,580	α, γ	Multiple n-capture
Pu-241	13.2	β, γ	Multiple n-capture
Pu-242	2.79×10^5	α	Multiple n-capture; daughter Am-242
Am-241	458	α, γ	Daughter Pu-241
Am-243	7950	α, γ	Multiple n-capture
Cm-243	32	α, γ	Multiple n-capture
Cm-244	17.6	α, γ	Multiple n-capture

Symbol	Generator
L	Light Water Reactors
F	Fuel Fabrication Facilities
U	UF_6 Conversion Plants
I	Institutional Facilities
N	Industrial Facilities

The streams were next divided into four general groups based upon common waste characteristics. The groups are: lightwater reactor process wastes, trash, low specific activity wastes, and wastes having unique special characteristics such as high activity. The grouping of waste streams was done to help increase the flexibility of the data base when considering the application of various waste processing techniques. Finally, six of the waste streams have been separated into two components and the additional six streams resulting from this separation have been denoted by a plus sign after the waste generator symbol (I or N) instead of the usual minus sign. This was done to identify the larger facilities (denoted by the minus sign) which could more easily implement their own waste treatment processes from smaller facilities (denoted by the plus sign) which cannot generally do the same. The as generated (untreated) isotopic concentrations for the various waste streams by group are shown in Table 3.3.

3.4.3.2 Volume of the Waste as Generated

NRC also analyzed currently available information about the current and projected rates of waste generation and calculated the volume of waste for each of the 36 waste streams projected to be generated on a regional basis. The regions used in the calculations correspond to the five NRC regions. The volume for each stream was projected from 1980 through the year 2000. Both high and low estimates of waste generation were considered. In developing the projections, nuclear fuel cycle waste volume was assumed to be proportional to the nuclear electrical generation capacity. Nonfuel cycle waste volumes were assumed to grow at a linear rate based upon least squares fit of existing data on individual waste streams. The "untreated" waste volumes assumed in this EIS are shown in Table 3.4.

3.4.3.3 Processing, Treatment and Packaging

NRC also analyzed the various types of processing and treatment options to which the waste, as generated, could be subjected that would change the as generated waste characteristics. Such processing and treatment could reduce the volume of the waste (e.g., compaction of trash, evaporation of liquids and incineration of combustible waste) or increase the volume of the waste (e.g., addition of absorbent materials to liquids and solidification of liquids with a media such as cement). Such processing would also change the chemical and physical properties of the waste as well as the activity concentration. Depending upon whether the processing or treatment option reduced or increased the volume of waste, volume decrease and increase factors were calculated for each stream processed based upon application of one of the above particular processing or treatment options.

Table 3.3 As Generated (Untreated) Isotopic Concentrations (Ci/m^3)

Group 1	P-IXRESIN	P-CONCLIQ	P-FSLUDGE	P-FCARTRG	B-IXRESIN	B-CONCLIQ	B-FSLUDGE
Total	3.36E-02	1.09E-01	1.06E+00	1.86E+00	4.63E00	2.77E-01	5.24E+00
H-3	2.66E-03	3.45E-03	2.59E-03	1.15E-03	1.92E-03	6.24E-04	1.26E-02
C-14	9.74E-05	1.27E-04	9.55E-05	4.25E-05	1.19E-03	3.89E-05	7.78E-04
FE-55	2.34E-03	2.27E-02	3.10E-01	5.55E-01	9.48E-01	7.60E-02	1.44E+00
NI-59	2.79E-06	2.71E-05	3.71E-04	6.60E-04	9.80E-04	7.85E-05	1.49E-03
CO-60	4.53E-03	4.40E-02	6.00E-01	1.07E+00	1.59E+00	1.27E-01	2.41E+00
NI-63	8.61E-04	8.36E-03	1.14E-01	2.04E-01	2.15E-02	1.72E-03	3.25E-02
NB-94	8.84E-08	8.58E-07	1.17E-05	2.09E-05	3.09E-05	2.48E-06	4.70E-05
SR-90	1.94E-04	2.52E-04	1.89E-04	8.40E-05	3.64E-03	1.18E-04	2.37E-03
TC-99	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
I-129	2.44E-06	3.16E-06	2.37E-06	1.06E-06	2.04E-04	6.65E-06	1.33E-04
CS-135	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
CS-137	2.19E-02	2.85E-02	2.14E-02	9.54E-03	2.04E+00	6.65E-02	1.33E+00
U-235	4.71E-08	6.15E-08	1.46E-07	3.64E-07	5.33E-08	3.44E-08	3.32E-07
U-238	3.71E-07	4.84E-07	1.15E-06	2.87E-06	4.20E-07	2.71E-07	2.61E-06
NP-237	9.06E-12	1.18E-11	2.81E-11	7.02E-11	1.02E-11	6.61E-12	6.38E-11
PU-238	2.60E-05	5.12E-05	4.76E-05	2.51E-04	8.34E-05	1.99E-04	4.66E-04
PU-239/240	1.82E-05	3.31E-05	1.55E-04	3.80E-04	5.34E-05	9.43E-05	2.36E-04
PU-241	7.94E-04	1.44E-03	6.75E-03	1.66E-02	2.60E-03	4.60E-03	1.15E-02
PU-242	3.99E-08	7.25E-08	3.39E-07	8.34E-07	1.17E-07	2.06E-07	5.18E-07
AM-241	1.87E-05	2.99E-05	2.64E-04	1.64E-04	2.32E-05	1.20E-04	1.56E-04
AM-243	1.26E-06	2.02E-06	1.78E-05	1.10E-05	1.57E-06	8.10E-06	1.05E-05
CM-243	9.92E-09	1.17E-08	3.10E-07	1.93E-07	2.70E-08	2.59E-07	2.97E-07
CM-244	1.38E-05	1.92E-05	1.77E-04	1.10E-04	1.82E-05	2.05E-04	2.24E-04

Table 3.3 (continued)

Group 2	P-COTRASH	P-NCTRASH	B-COTRASH	B-NCTRASH	F-COTRASH	F-NCTRASH	I-COTRASH	N-SSTRASH	N-LOTRASH
Total	2.28E-02	5.25E-01	2.35E-02	3.79E+00	5.58E-06	5.33E-06	1.13E-01	1.12E-05	3.53E-02
H-3	3.04E-04	6.99E-03	6.75E-05	1.09E-02	0	0	9.13E-02	0	2.85E-02
C-14	1.12E-05	2.57E-04	4.17E-06	6.73E-04	0	0	5.26E-03	0	1.64E-03
FE-55	5.97E-03	1.37E-01	6.01E-03	9.69E-01	0	0	0	0	0
NI-59	7.11E-06	1.64E-04	6.21E-06	1.00E-03	0	0	0	0	0
CO-60	1.15E-02	2.65E-01	1.01E-02	1.62E-00	0	0	1.04E-02	0	3.25E-03
NI-63	2.19E-03	5.05E-02	1.36E-04	2.19E-02	0	0	0	0	0
NB-94	2.25E-07	5.18E-06	1.96E-07	3.16E-05	0	0	0	0	0
SR-90	2.22E-05	5.11E-04	1.27E-05	2.05E-03	0	0	1.45E-03	0	4.53E-04
TC-99	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0	0	3.39E-09	0	1.06E-09
I-129	2.78E-07	6.41E-06	7.14E-07	1.15E-04	0	0	0	0	0
CS-135	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0	0	0	0	0
CS-137	2.51E-03	5.78E-02	7.14E-03	1.15E+00	0	0	4.56E-03	0	1.42E-03
U-235	7.89E-09	1.82E-07	1.22E-09	1.97E-07	1.18E-06	1.13E-06	0	2.36E-06	0
U-238	6.22E-08	1.43E-06	9.60E-09	1.55E-06	4.40E-06	4.20E-06	0	8.80E-06	0
NP-237	1.52E-12	3.49E-11	2.35E-13	3.78E-11	0	0	0	0	0
PU-238	5.97E-06	1.38E-04	2.30E-06	3.71E-04	0	0	0	0	0
PU-239/240	5.53E-06	1.27E-04	1.16E-06	1.86E-04	0	0	0	0	0
PU-241	2.41E-04	5.55E-03	5.63E-05	9.08E-03	0	0	0	0	0
PU-242	1.21E-08	2.79E-07	2.53E-09	4.08E-07	0	0	0	0	0
AM-241	3.96E-06	9.12E-05	9.67E-07	1.56E-04	0	0	0	0	0
AM-243	2.67E-07	6.15E-06	6.52E-08	1.05E-05	0	0	0	0	0
CM-243	2.74E-09	6.30E-08	1.93E-09	3.12E-07	0	0	0	0	0
CM-244	2.61E-06	6.00E-05	1.49E-06	2.41E-04	0	0	0	0	0

Table 3.3 (continued)

Group 3	F-PROCESS	U-PROCESS	I-LQSCNVL	I-ABSLIQD	I-BIOWAST	N-SSWASTE	N-LOWASTE
Total	1.08E-04	3.80E-04	9.60E-03	1.99E-01	2.06E-01	2.11E-02	
H-3	0	0	5.01E-03	1.42E-01	1.75E-01	0	1.63E-02
C-14	0	0	2.51E-04	8.16E-03	1.01E-02	0	9.36E-04
FE-55	0	0	0	0	0	0	0
NI-59	0	0	0	0	0	0	0
CO-60	0	0	0	3.12E-02	3.99E-03	0	1.47-03
NI-59	0	0	0	0	0	0	0
NB-63	0	0	0	0	0	0	0
SR-90	0	0	4.34E-03	4.34E-03	8.33E-03	0	1.31E-03
TC-99	0	0	0	1.02E-08	6.51E-09	0	7.76E-10
I-129	0	0	0	0	0	0	0
CS-135	0	0	0	0	0	0	0
CS-137	0	0	0	1.37E-02	8.76E-03	0	1.04E-03
U-235	2.30E-05	1.65E-05	0	0	0	4.60E-05	0
U-238	8.54E-05	3.64E-04	0	0	0	1.71E-04	0
NP-237	0	0	0	0	0	0	0
PU-238	0	0	0	0	0	0	0
PU-239/240	0	0	0	0	0	0	0
PU-241	0	0	0	0	0	0	0
PU-242	0	0	0	0	0	0	0
AM-241	0	0	0	0	0	0	0
AM-243	0	0	0	0	0	0	0
CM-243	0	0	0	0	0	0	0
CM-244	0	0	0	0	0	0	0

Table 3.3 (continued)

Group 4	L-NFRCOMP	L-DECONRS	N-ISOPROD	N-HIGHACT	N-TRITIUM	N-SOURCES	N-TARGETS
Total	4.04E+03	1.56E+02	1.50E+01	2.10E+02	2.33E+03	5.76E+03	8.04E+01
H-3	0	1.08E-02	4.20E-02	0	2.33E+03	8.63E+02	8.04E+01
C-14	2.59E-01	5.13E-04	4.51E-05	1.32E-02	0	5.76E+02	0
FE-55	2.23E+03	4.05E+01	0	1.15E+02	0	0	0
NI-59	1.40E+00	4.49E-02	0	6.56E-02	0	0	0
CO-60	1.60E+03	7.28E+01	0	8.48E+01	0	1.73E+03	0
NI-63	2.09E+02	3.69E+00	0	1.06E+01	0	2.30E+02	0
NB-94	8.19E-03	1.42E-03	0	4.47E-04	0	0	0
SR-90	0	4.28E-02	6.27E+00	0	0	1.15E+03	0
TC-99	0	1.20E-05	3.27E-04	0	0	0	0
I-129	0	3.34E-05	2.72E-06	0	0	0	0
CS-135	0	1.20E-05	3.27E-04	0	0	0	0
CS-137	0	3.18E-01	3.73E+00	0	0	1.15EE+03	0
U-235	0	6.84E-05	1.02E-05	0	0	0	0
U-238	0	5.40E-04	3.81E-05	0	0	0	0
NP-237	0	1.32E-08	5.33E-13	0	0	0	0
PU-238	0	1.34E+00	1.97E-04	0	0	0	0
PU-239/240	0	1.77E+00	5.55E-05	0	0	0	0
PU-241	0	3.55E+01	7.10E-03	0	0	0	0
PU-242	0	3.87E-03	9.57E-08	0	0	0	0
AM-241	0	5.29E-03	1.10E-05	0	0	5.76E+02	0
AM-243	0	3.59E-04	1.25E-06	0	0	0	0
CM-243	0	3.46E-04	1.65E-04	0	0	0	0
CM-244	0	3.27E-03	2.88E-07	0	0	0	0

Table 3.4 As Generated (Untreated) Waste Volumes Projected to be Generated-1980 to the Year 2000 (m^3)

	Region 1		Region 2		Region 3		Region 4*	
	Vol.	%	Vol.	%	Vol.	%	Vol.	%
P-IXRESIN	6.93E+03	0.79	1.30E+04	1.34	6.59E+03	1.00	8.14E+03	1.25
P-CONCLIQ	4.87E+04	5.54	9.12E+04	9.45	4.63E+04	7.06	5.72E+04	8.79
P-FSLUDGE	8.56E+02	0.10	1.60E+03	0.17	8.14E+02	0.12	1.01E+03	0.15
P-FCARTRG	4.35E+03	0.50	8.16E+03	0.84	4.14E+03	0.63	5.12E+03	0.79
B-IXRESIN	2.10E+04	2.39	2.51E+04	2.60	2.05E+04	3.12	9.67E+03	1.49
B-CONCLIQ	5.79E+04	6.59	6.93E+04	7.17	5.64E+04	8.60	2.67E+04	4.10
B-FSLUDOE	4.65E+04	5.30	5.57E+04	5.77	4.54E+04	6.92	2.14E+04	3.30
P-COTRASH	8.49E+04	9.66	1.59E+05	16.47	8.07E+04	12.31	9.97E+04	15.33
P-NCTRASH	4.36E+04	4.96	8.16E+04	8.45	4.14E+04	6.32	5.12E+04	7.87
B-COTRASH	5.74E+04	6.54	6.87E+04	7.12	5.60E+04	8.54	2.65E+04	4.07
B-NCTRASH	2.72E+04	3.10	3.26E+04	3.38	2.66E+04	4.05	1.26E+04	1.93
F-COTRASH	4.72E+04	5.37	1.18E+05	12.22	0	0	7.08E+04	10.88
F-NCTRASH	8.34E+03	0.95	2.09E+04	2.16	0	0	1.25E+04	1.92
I-COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
I+COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
N-SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N+SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N-LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
N+LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
F-PROCESS	1.56E+04	1.78	3.91E+04	4.05	0	0	2.34E+04	3.61
U-PROCESS	0	0	0	0	1.41E+04	2.14	1.41E+04	2.16
I-LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I+LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I-ABSLTQD	1.73E+03	0.20	1.23E+03	0.13	1.51E+03	0.23	1.12E+03	0.17
I+ABSLIQD	1.73E+03	0.20	1.23E+03	0.13	1.51E+03	0.23	1.12E+03	0.17
I-BIOWAST	4.87E+03	0.55	3.46E+03	0.36	4.24E+03	0.65	3.14E+03	0.48
I+BIOWAST	4.87E+03	0.55	3.46E+03	0.36	4.24E+03	0.65	3.14E+03	0.48
N-SSWASTE	3.17E+04	3.61	6.34E+03	0.66	1.27E+04	1.93	1.27E+04	1.95
N-LOWASTE	1.81E+04	2.06	1.21E+04	1.25	1.81E+04	2.76	1.21E+04	1.85
L-NFRCOMP	6.48E+02	0.07	1.04E+03	0.11	6.22E+02	0.09	5.77E+02	0.09
L-DECONRS	7.35E+03	0.84	1.22E+04	1.27	8.05E+03	1.23	7.35E+03	1.13
N-ISOPROD	5.20E+03	0.59	0	0	0	0	0	0
N-HIGHACT	8.09E+02	0.09	5.74E+02	0.06	7.04E+02	0.11	5.22E+02	0.08
N-TRITIUM	2.65E+03	0.30	2.09E+02	0.02	2.09E+02	0.03	4.18E+02	0.06
H-SOURCES	5.78E+01	0.01	4.10E+01	0.00	5.04E+01	0.01	3.73E+01	0.01
N-TARGETS	4.16E+02	0.05	2.95E+02	0.03	3.62E+02	0.06	2.68E+02	0.04
TOTAL	8.78E+05		9.66E+05		6.56E+05		6.50E+05	

*NRC Regions 4 and 5 are combined such that each region generates up to 10^6 m^3 of waste.

Three types of solidification processes or scenarios were assumed for this EIS as follows:

- Scenario A assumes continuation of existing practices resulting in waste performance characteristics which are comparatively less desirable than the following two types. Scenario A solidification is simulated by assuming that 50 percent of the waste stream is solidified using urea-formaldehyde systems and the other 50 percent using cement systems.

- Scenario B assumes improved waste performance characteristics over the previous case. Scenario B solidification is simulated by assuming that 50 percent of the waste stream is solified using cement systems and the other 50 percent using improved synthetic polymer systems.

- Scenario C assumes further improved waste performance characteristics achievable with currently available technology. Scenario C solidification is simulated by assuming that the waste stream is all solidified using improved synthetic polymer systems.

To characterize the change and variation in chemical and physical properties of the waste resulting from application of the processing or treatment options, NRC developed and applied 6 waste form indices: (1) Flammability--the ability of the waste form to catch fire and support combustion; (2) Dispersibility--the dispersibility of the waste form several decades after disposal; (3) Stability-the structural stability of the waste; (4) Leachability--the resistance of the waste form to leaching; (5) Chemical content--the content of chemicals such as chelating agents that could increase mobility; and (6) Accessibility--the accessibility of the radionuclides in the waste to transport by wind and water. NRC also analyzed the type of packaging that could be applied to the various waste streams. The various types of packaging assumed is reviewed in the next subsection. Finally data on the cost, occupational exposures, population exposures and energy use (i.e., gallons of fuel consumed) were calculated for each waste processing and treatment option. It is used in the alternatives analysis to account for the application of specific processing and treatment options to the various waste streams.

3.4.3.4 Waste Spectra

Although it is convenient to characterize wastes by stream for each waste generator, the waste disposed of at a disposal site never consists of just one stream. Rather, it consists of a cross section of all of the streams and there may be large differences between streams and within individual streams regarding the types of processing, treatment and packaging that is used. Thus, there is an infinite number of different types of wastes, in different types of forms, and in different types of packaging that could be shipped for disposal. To bound the range in waste that might be expected to be generated and disposed of, four "waste spectra" were derived. Each waste spectrum represents a cross section of all the waste streams that might be generated and shipped for disposal under specific conditions of treatment and processing. Each spectrum is defined in terms of the total waste volume, waste performance and radionuclide concentrations that result from the application of a specific combination of waste treatment and processing options to specific waste streams. The spectra thus bound the range in waste that might be expected to be generated and disposed of. Four spectra were developed to characterize a range of alternative waste form properties and processing options from a continuation of existing and some past practices with little additional increase effort and cost to extreme volume reduction and improved waste form at very high effort and cost. Waste Spectrum No. 1 characterizes a continuation of existing and some past waste management practices and is used along with the base case site to calculate base case costs and impacts. Waste Spectrum No. 2 characterizes improvements in the form of the waste through processing and reduction in waste volume with modest expenditures of time and money. No. 3 characterizes further waste form improvements and volume reduction at further increased costs. No. 4 characterizes the maximum volume reduction and improved waste form that can currently be practically achieved. Waste being disposed of today falls between waste spectra Nos. 1 and 2, with the trend moving toward spectrum 2. Implementation of license conditions in effect at the existing sites regarding solidification of higher activity wastes would place the waste very close to waste spectrum No. 2. The four spectra are summarized in Table 3.5.

3.4.3.5 Impact Measures

Impact measures calculated by NRC for the generation and processing of waste include cost for processing and treatment; occupational exposures incurred during processing and treatment; population exposures resulting from processing and treatment and energy use (e.g., gallons of fuel consumed during processing and treatment). The costs for waste processing change from spectra 1 to 4 due to the greater application of processing options such as incineration. Processing options also have an impact on transportation costs, (discussed in the next subsection), since the volume of waste requiring packaging and transport can change depending upon the processing option used. The details of the description and characterization of waste, processing options, cost and impact data, and development of waste spectra is set out in Appendices D and G.

3.5 WASTE TRANSPORTATION AND PACKAGING

In addition to those generating the waste, there are a number of firms which supply intermediate services between the waste generator and disposal facility. These firms supply packaging for waste, assist in preparation of waste shipments, transport waste to disposal facilities and in some cases carry out waste processing and treatment operations at generator facilities.

Important to transportation is the size and type of packaging used for various types of waste; the type of transport vehicles and shielded overpacks used for transportation; miles travelled; and the degree of care involved in transportation and handling of waste during loading, unloading and emplacement at a

Table 3.5 Summary Description of Waste Spectra

Waste Spectrum 1

This spectrum assumes a continuation of existing and some past waste management practices. Some of the LWR wastes--namely P-CONCLIQ, B-CONCLIQ, and L-DECONRS waste streams--are solidified. However, no processing is done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be shipped to disposal sites in a dewatered form. LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified with various media designated as solidification scenario A. No special effort is made to compact trash. Institutional waste streams are shipped to disposal sites after they are packaged with currently utilized absorbent materials. Resins from LWR decontamination operations (L-DECONRS stream) are solidified in a media with highly improved characteristics (solidification scenario C).

Waste Spectrum 2

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification scenario B). LWR concentrated liquids are additionally reduced in volume through an evaporator/crystallizer. All LWR concentrated liquids are evaporated in 50 weight percent solids, and all LWR process wastes are solidified using solidification scenario B procedures. In the case of cartridge filters, the solidification agent fills voids in the packaged waste but does not increase the volume. Liquid scintillation vials are crushed at large facilities and packed in absorbent material. All compactible trash streams are compacted; P-COTRASH, B-COTRASH, F-COTRASH, I-COTRASH, N-SSTRASH, and L-LOTRASH streams are compacted at the source of generation; and I+COTRASH, N+SSTRACH, and N+LOTRASH streams are compacted at the disposal facility. Liquids from medical isotope production are solidified using solidification scenario C procedures.

Waste Spectrum 3

In this spectrum, LWR process wastes are solidified assuming that further improved waste solidification agents are used (solidification scenario c). LWR concentrated liquids are first evaporated to 50 weight percent solids. All possible incineration of combustible material (except LWR process wastes) is performed; some incineration is done at the source of generation (fuel cycle trash, LWR decontamination resins, institutional wastes from large facilities and industrial trash from large facilties) and some at the disposal site (institutional and industrial trash from small facilities). All incineration ash is solidified using solidification scenario C procedures.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All wastes amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification scenario C procedures; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All noncompactible wastes are reduced in volume at the disposal site or at a central processing facility using a large hydraulic press. This spectrum represents the maximum volume reduction that can currently be practically achieved.

disposal facility. These latter aspects were considered together since the type of waste, its packaging size, radiation levels and other factors uniformly affect handling at the point of generation, during loading onto a transport vehicle, during transportation to the disposal site and during unloading and disposal operations at the disposal site.

3.5.1 Description of Services Provided

As discussed, several types of goods and services can be provided by various service organizations depending on individual generator needs, the composition of the waste, its volume and its frequency of generation. Transportation can be provided by common or contract carriers which pick up packaged waste at generator facilities and transport it to the point of disposal. In such cases, the carrier is providing only a transportation service and the shipper retains responsibility for the wastes until accepted at the disposal facility. Transportation can also be provided by the licensee generating the waste or by other private carriers which accept title to the waste upon receipt at a generator's facility. These firms are licensed by the NRC or an Agreement State for their possession of the waste and in some cases they provide other services such as supplying packaging, waste processing, and temporary storage.

For larger generators like nuclear power plants, these service activities generally consist of providing the necessary shipping containers, (e.g., shielded casks), transporting the waste to the disposal site, and in some cases, waste processing. Such large generators usually contract these services out to private firms specializing in the provision of such services. In these instances, the cask is usually leased on an as-needed basis and the truckloads of waste are transported directly from the generator to the disposal site. A return trip is normally required to return the empty shielded cask back to the generator to allow it to be refilled for the next shipment. Often, the rental of the cask and the actual transportation are performed by separate companies.

Smaller LLW generators such as educational institutions , hospitals, and many industries will use common, contract, or private carriers. In many cases, a firm collects the LLW from a number of small generators and transports it to a central, temporary storage facility. Here the wastes may be repackaged and consolidated until sufficient waste has been collected to make up a truckload. At this point, the wastes will be transported for disposal. Firms engaged in this collection and consolidation of waste are often referred to as "waste brokers" and can generate full truckloads with sufficient frequency so as to achieve much high equipment utilization rates and lower unit transport costs than smaller LLW generators can on their own.

The assumptions and organization of data regarding the type of packaging and services provided, transport vehicles used, frequency of shipments, and other data is described below. Further detail is set out in Appendices D and G.

3.5.2 Degree of Care Required in Handling the Waste and the Shielding Required During Transportation

Each waste stream contains different amounts of different radionuclides and thus emits different types of radiation at different levels. Also, depending on the package size and the amount of waste contained in a package, different waste packages have different surface radiation levels. The external radiation levels at the package surface affects the level of care that should be exercised during handling of the waste and the type of shielding that would be required during transportation to comply with existing DOT and NRC transportation regulations. To characterize the broad range in package surface radiation levels that would be presented by the various waste streams packaged in various packages, NRC established three categories to represent the level of care required to handle each waste stream based on the total activity and radiation emitted by each stream. These categories are denoted by:

- Those requiring regular care--i.e., those streams containing very little high energy gamma emitting radionuclides and thus very low external radiation levels;
- Those requiring extreme care--i.e., those streams containing large quantities of high energy gamma emitting radionuclides and thus very high external radiation levels; and
- Those streams in between the above and requiring special care--i.e., those streams containing some high-energy gamma emitting radionuclides and thus moderate external radiation levels.

Since the activity of individual waste streams can vary, NRC also estimated the fraction of each waste stream requiring a particular level of care based on the variation in activity. This would account for the normal variation expected in waste stream activity.

3.5.3 Type of Packaging Used

After determining the level of care, NRC also analyzed the different types of packaging that could be used for shipment and disposal of waste. Based on this analysis the packaging was generalized into 5 generic types of packaging as follows:

1. Large wooden boxes - 128 ft^3
2. Small wooden boxes - 16 ft^3
3. 55-gallon drums - 7.5 ft^3
4. Small liners - 50 ft^3
5. Large liners - 170 ft^3

NRC assumed, for purposes of this analysis, that "extreme care" wastes were only packaged in drums or liners which are remotely manipulated during loading and off-loading. "Regular" and "special" care wastes are assumed to be packaged in all 5 package types.

Finally, NRC determined the fractional use of each package type for each waste stream using available shipping and survey data.

3.5.4 Mode of Shipment

In the same way that there are a large number of package types that can be used for shipment and disposal of the waste, there are also a number of different shipment modes, vehicles and shielded overpaks that can be used to transport the waste to the disposal site. For purposes of this EIS, NRC conservatively assumed that all waste is transported to the disposal facility by truck (i.e., rail and barge transport are not used). NRC generalized the various types of transport vehicles and overpaks into 6 types:

1. Vans
2. Flatbed trailers
3. Shielded trailers
4. Large shielded casks
5. Small shielded casks
6. 1-drum shielded casks

Casks are assumed to be transported to the disposal facility on flatbed trailers.

Since the activity and packaging used for each waste stream varies, and also varies within each waste stream as noted above, NRC also determined the percentage use of different vehicles and overpaks for the transport of the various streams.

3.5.5 Impact Measures

Impact measures calculated by NRC for the packaging and transport of waste include cost, occupational exposures, population exposures and energy use. Cost was calculated including a mileage charge (and fuel surcharge), a cask rental charge, and an overweight shipment transportation charge. Energy use was calculated based on the total shipment miles, including empty cask return trips, and using an average fuel consumption rate of 6 miles/gallon. For the base case and alternatives analysis, transportation distance was not assumed to vary. Costs and impacts are calculated assuming an average distance of 400 miles from the point of waste generation to the waste disposal facility. Occupational and population exposures incurred during transportation were calculated based on total loaded miles and the number of loaded shipments (Return trips in which the vehicle was empty were excluded). Occupational exposures incurred during loading of the waste and during transportation are included together. The exposures were calculated based on the man-minutes required to load each package and the radiation field associated with each type of package handling environment. Occupational exposures were calculated for each waste care level, package type and shipment mode. Occupational exposures during unloading and disposal of the waste were also calculated based on the personnel time required to unload and dispose of the wastes and the assumed radiation fields associated with the handling environment that the workers are exposed to.

3.6 WASTE DISPOSAL

This section describes the affected environment made up of those owning and operating the disposal sites. It also describes the siting, licensing, design, operation, closure and postoperational activities of a reference base case LLW disposal facility.

The operators of LLW disposal sites offer the essential services of providing a licensed and controlled site where generators of LLW may dispose of their wastes. The sites are owned by the state or federal government. The facilities and procedures necessary to offer this service include the monitoring of transport vehicles and packages to verify compliance with established license conditions and regulations; off-loading, temporary storage and disposal of the wastes; and monitoring and surveillance of the disposed wastes throughout the operating lifetime of the site. Lease conditions between the operators and state landlords provide that states will assume reponsibility for the long-term control and surveillance of the sites after closure. The conditions also include provisions for the accrual of funds to pay for the state's long-term custodial responsibilities.

There are presently three operating, licensed commercial LLW disposal facilities. These are the Barnwell, South Carolina site operated by Chem-Nuclear Systems, Inc. and the Beatty, Nevada and Richland, Washington sites operated by U.S. Ecology, Inc. All three of the above sites are located in Agreement States and are sited on state-owned land, except the Richland site. In this case the site is located on federally-owned land that has been leased to the state of Washington. As noted earlier in Chapter 1, three other licensed, commercial LLW sites exist which are not currently operating. These are the Sheffield, Illinois; Maxey Flats, Kentucky; and West Valley, New York sites. The first two sites were operated by the Nuclear Engineering Company and the last was operated by Nuclear Fuel Services, Inc., a subsidiary of the Getty Oil Company.

Both LLW site licensees offer similar onsite services concerning the disposal of LLW. These include explicit criteria concerning the types of wastes acceptable for burial, as well as specifications for solidification agents permitted, packaging requirements and permissible activity levels. They survey incoming shipments for compliance with license requirements and DOT transportation and packaging criteria. Also, wastes may be segregated by type and activity level to increase safety and operational efficiency. Transportation services and shielded shipping casks for lease to LLW generators that produce wastes with higher activity levels may also be provided.

3.6.1 Characterization of a Reference Base Case LLW Disposal Facility for Purposes of EIS Analysis

To help provide conservative bounds to the potential costs and impacts of waste disposal, NRC characterized a reference LLW disposal facility that is assumed to be sited in a humid eastern environment. NRC staff anticipates that over the next 20 years, over three-quarters of the waste generated in the United States will be generated in humid environments, i.e., in the eastern and humid midwestern sections of the country. Regional disposal of waste therefore implies that most of the waste generated in humid environments would also be disposed in humid environments. Potential ground-water impacts (and actions required to protect ground water) at a humid site are generally expected to be greater than those at an arid area. Some of the conditions at an eastern humid site which would indicate this include the relatively higher annual precipitation, shallower depths to ground water, and relatively shorter distances from the disposed waste to the point of ground-water discharge into surface streams.

The reference facility is sized to accept a relatively large quantity of waste--i.e., 50,000 m^3 of waste per year over a 20-year operating life, or a total volume of one million m^3. This corresponds to approximately one-quarter of the total volume of LLW projected in the United States to the year 2000. Disposal of one million m^3 of waste in the reference facility will require about 150 acres of land, which corresponds to an approximate upper bound of the land area of current commercial disposal facilities.

The site for the facility minimally meets all of the site suitability requirements set out in Chapter 5. The facility is also assumed to be operated in compliance with minimum radiation safety practices required by provisions of 10 CFR Part 20 (see Chapter 6). Although the facility is assumed to comply with the NRC Branch Technical Position on Site Closure and Stabilization (See Appendix I), no special effort is, however, assumed to be made during operations at the reference facility regarding the form of waste or design and operational practices to ensure long-term site stability. Several design and operational improvements directed at stability that have been instituted at some existing sites have not been assumed for the base case site, (e.g., vibratory compaction of backfill material). This has been done to establish a base case level of long-term costs and radiological impacts against which measures to improve site performance, achieve greater site stability, minimize radiological impacts, and to ensure adequate funding can be assessed. Figure 3.1 describes the life cycle of a typical disposal facility. Further information regarding design, operation, and closure of the facility is set out below. The details are described in Appendix E.

3.6.2 Facility Design

A conceptual layout of the reference disposal facility is illustrated in Figures 3.2 and 3.3. As shown in the figures, the disposal facility is divided into two basic areas: a "restricted area" and an "administration area."

The entire site is surrounded by a 2.4 m (8 ft) high chain-link fence topped with three strands of barbed wire. A 2.4 m high fence also separates the administration area from the restricted area. Access to the disposal site is via a state highway running close to the site from which two short gravel roads lead onto the disposal facility. Access to the restricted area is controlled by security check points near the gates in the fence separating the administration area and the restricted area.

Figure 3.1 Life Cycle of a Typical Near-Surface Disposal Facility

Number of Years	Activity	Description
1-2 Years	Site Selection and Characterization.	Site selection and characterization activities are carried out by the applicant in coordination with NRC, and state and local government. A preferred site is selected, and the site characterized in detail. A license application is prepared which includes a preliminary closure plan, environmental report, arrangements for government ownership of the land, lease arrangements for use of the site, and financial arrangements to cover the costs of closure and postclosure activities.
1-2 Years	Preoperational Licensing	The application is submitted to NRC (including a license fee) and docketed. A notice of receipt of the application is published in the Federal Register and an opportunity for requesting hearings is provided. State and local government officials are notified. An analysis of the application is carried out by the NRC licensing staff including preparation of an environmental impact statement. If no hearings are requested and upon a satisfactory licensing finding, NRC takes action to issue the license. A Notice of Issuance is published in the Federal Register and state and local government officials are notified. If hearings are requested, hearings are held including any Commission reviews and appeals. Upon resolution of all hearings and appeals and upon a satisfactory finding, NRC issues the license, publishes notices and notifies state and local governmental officials.

Figure 3.1 (Continued)

Number of Years	Activity	Description
20-40 Years	Construction and Active Disposal Operations	Upon issuance, the operator begins operations to construct the facility and to receive and disposal of waste. On a periodic basis--about every 5 years, or as stated in the license--NRC reviews the licensee's program including the preliminary site closure plan, financial arrangements for closure and post-closure activities, and continued assessment of environmental impacts.
1-2 Years	Site Closure and Stabilization	During the operating phase, the site is generally stabilized as it is filled (e.g., trench caps are put in place). At closure, final site stabilization activities are carried out. Facilities not needed for postclosure activities are decontaminated and dismantled. Costs for closure are provided by financial arrangements of the operator. Upon satisfactory closure, NRC terminates the license and control over the site reverts back to the government landowner.
100 Years	Institutional Control	The government landowner carries out custodial care of the site which includes continued government ownership and control of the site; carrying out activities such as posting, maintaining site security, monitoring of the environment, and carrying out any maintenance activities such as correction of subsidence depressions in trench covers due to consolidation of the waste. The terms and conditions of the lease and financial arrangements between operator and owner provide funds to cover the cost of these activities.

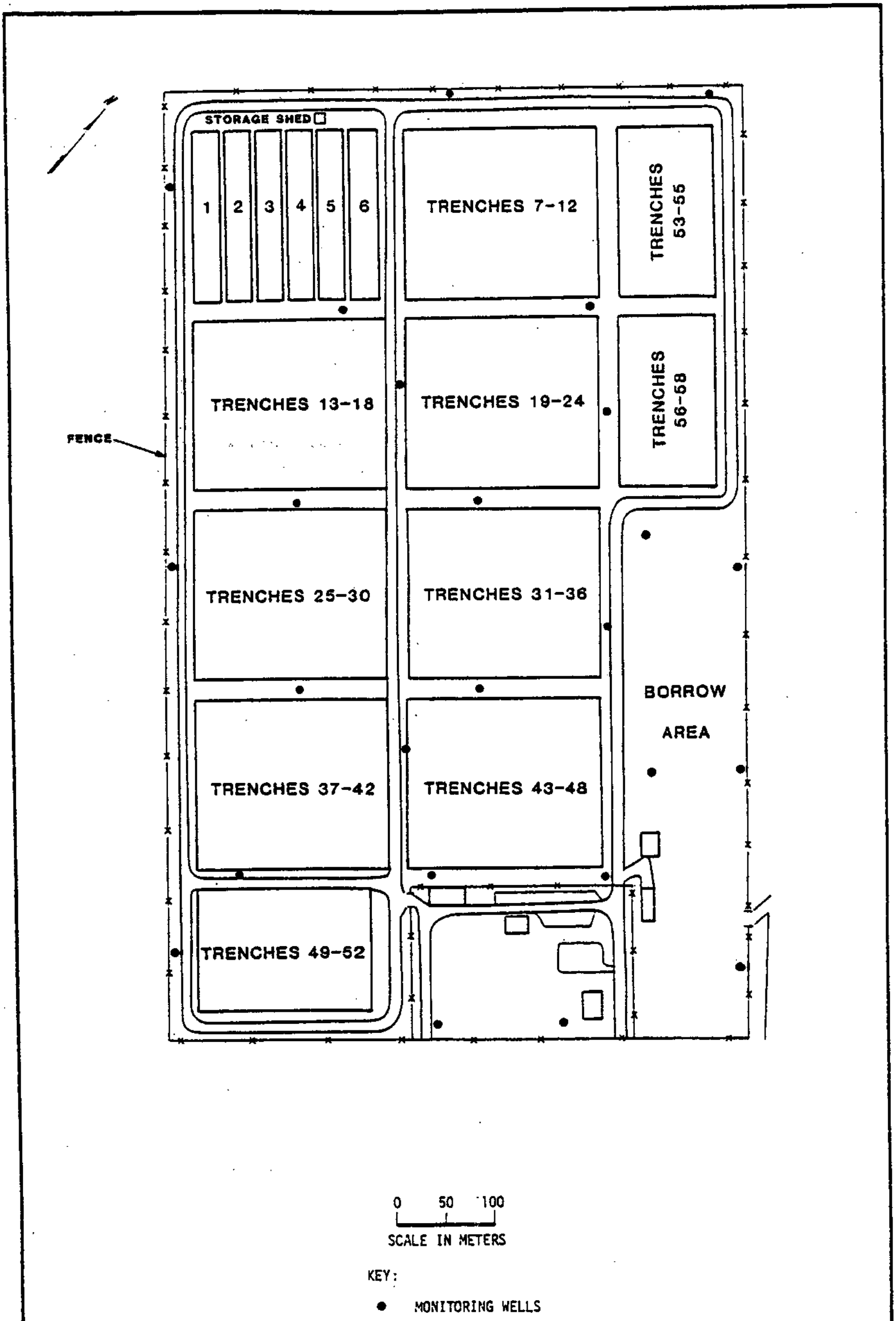


Figure 3.2 Conceptual Disposal Facility Layout

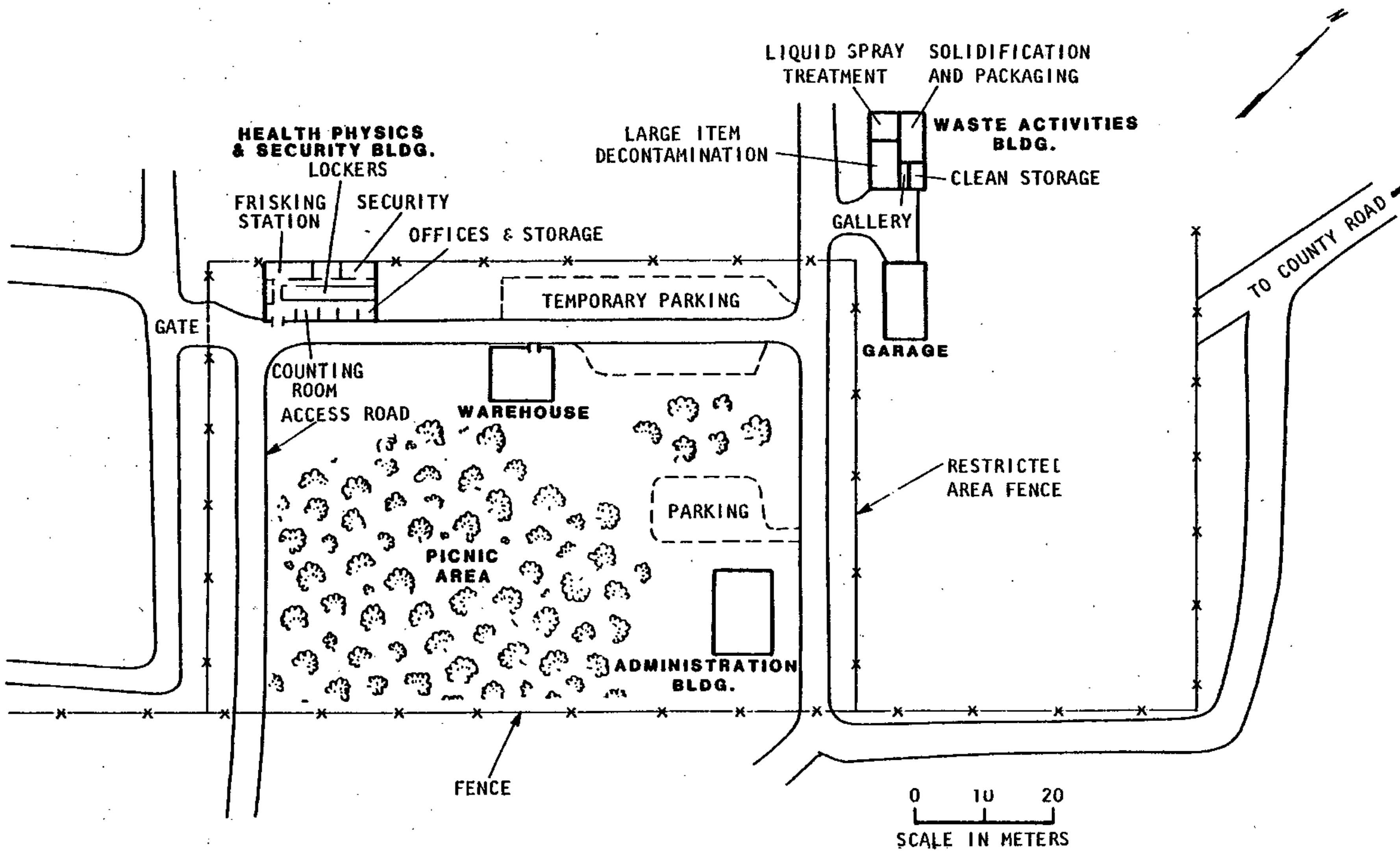


Figure 3.3 Conceptual Layout of Support Facilities

The disposal area at the reference facility includes 58 disposal trenches with average approximate dimensions of 180 m (591 ft) long, 30 m (100 ft) wide, and 8 m (26 ft) deep (see Figure 3.4). The rather large trench sizes assumed are representative of recent trends at existing disposal sites. A trench wall slope of 1 horizontal to 4 vertical (1:4) is assumed and the trenches are assumed to be separated by 3 m thick walls.

As a trench is constructed, the locations of the four corners of the trench are surveyed and referenced to a bench mark. An approximate one degree slope is provided in the bottom of a trench from end to end and from one side towards a 0.6 m x 0.6 m (2 ft x 2 ft) gravel filled French drain. The French drain runs the entire length on the lower elevation side to provide for collection of any liquid drainage that might occur. A gravel-filled sump is located at the low corner of the trench. Each trench is also equipped with a minimum of three 0.15 m (6 in) diameter polyvinyl chloride (PVC) standpipes located within the French drain and standing along the sidewalls of the trench.

Support facilities and structures include: (1) an administration building, (2) a health physics/security building, (3) a warehouse, (4) a garage, (5) a waste activities building, and (6) a storage shed. All structures at the site are one-story metallic structures on concrete pad foundations.

3.6.3 Facility Operations

The disposal facility is assumed to be operated for profit by a small corporation which is engaged in other nuclear-related business activities in addition to operating the disposal facility. Overall control of radiation health and safety at the corporate level is under the control of the senior radiation safety officer, who is responsible for conducting periodic reviews of site operations for compliance with health and safety regulations and license conditions, including periodic site inspections and audits. Operations at the disposal site are under the overall direction of a site manager and assistant site manager and have been divided into eight categories: the receipt, inspection, handling, storage, and disposal of waste; radiation and contamination control; site groundskeeping and maintenance; radiation safety and contamination control; environmental monitoring; security; recordkeeping and reporting; and quality assurance.

3.6.3.1 Waste Receipt and Inspection

Shipments of radioactive waste arrive by truck and are processed onto the site on a first-come, first-served basis. Accompanying the shipments are manifest documents--termed radioactive shipment records (RSRs)--which describe the content of the shipment. (An example of an RSR used at one disposal site is included in Appendix E.) Arriving shipments are inspected for compliance with applicable federal regulations and waste acceptance criteria established as conditions in the disposal site license.

Applicable federal regulations include those promulgated by NRC and DOT regarding waste packaging requirements, labelling requirements, vehicle placarding requirements, and allowable direct radiation and removable contamination levels at an accessible surface of transport vehicles.

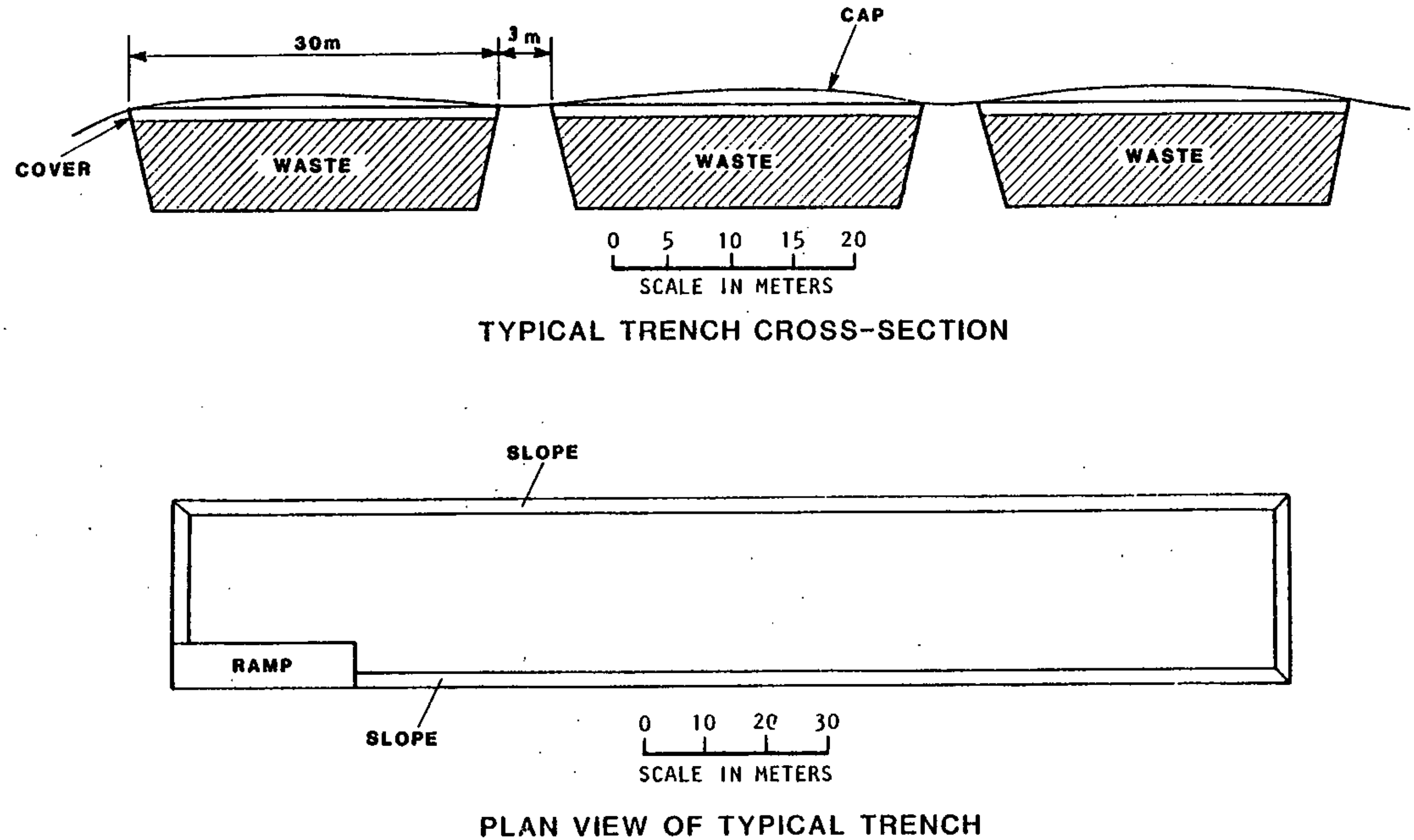


Figure 3.4 Details of Typical Disposal Trench

Shipments found to be in compliance with federal regulations and license conditions proceed into the disposal area for unloading. Depending upon license conditions, damaged or leaking waste containers may be overpacked or repackaged, and either accepted for disposal or returned to the sender. Activities such as overpacking and solidification are performed at the waste activities facility.

3.6.3.2 Waste Storage

Generally waste received at the site is disposed of within a few days. Waste that must be temporarily stored is generally left in transport vehicles or in temporary onsite storage areas.

3.6.3.3 Waste Disposal

Waste is randomly emplaced in the trench, sometimes using cranes and forklifts, and backfilled with dirt removed during trench excavation. Random waste emplacement results in a trench volume use efficiency of about 50 percent. Waste is not allowed to extend more than 100 feet beyond the backfilled portion of the trench. Backfill operations also commence if radiation readings greater than 100 mR/hr are recorded at the trench boundary, and continue until radiation levels are reduced below 100 mR/hr. Disposal commences at the high end of the trench and works down towards the lower end to prevent waste packages from being placed in water. Rainwater falling within the open trench drains away to the lower end of the trench where it can be removed.

Waste is emplaced to within one meter of the top of the trench, Earthen fill is then backfilled into the trench until the trench cover approximately corresponds to the original grade of the site surface. A one-meter thick cap composed of originally excavated soils is then placed upon the backfill and is mounded. No special compaction is performed on the fill and clay caps other than that provided by heavy earth moving equipment driven over the top of the cap. The cap is then covered with natural overburden material as necessary to provide good drainage characteristics and according to the final contours planned for the site surface. The overburden is reseeded to promote growth of a short-rooted grass cover.

Following trench capping, the disposal trenches are each marked with a monument which is inscribed with the following information:

- o A trench identification number;
- o Total trench activity of byproduct material in curies, and source and special nuclear material in grams;
- o Date of completion of disposal into the trench; and
- o Volume of waste in the trench.

In addition, each of the four top corners of the disposal trench are marked with a marker stone.

During waste handling and disposal, operations are monitored to ensure radiation safety. After the transport vehicle is unloaded it is again surveyed for contamination and decontaminated, as necessary, prior to leaving the restricted area. The results of the survey are recorded on the accompanying RSR.

3.6.3.4 Site Groundskeeping and Maintenance

Groundskeeping includes both the upkeep of grounds and the maintenance of external building surfaces. The purpose of groundskeeping is to promote site integrity by maintaining proper contour and soil conservation practices, by properly maintaining external structures and site systems, and by overseeing closed burial trenches in an efficient manner. Groundskeeping activities include countouring of the ground surface, emplacement of a soil cover material such as grass, fertilizing, mowing, and site drainage.

A site maintenance program entails routine inspection of site surfaces and fences for trench settlement, gullying, damage and debris. Repairs are made as necessary.

An important part of the reference site groundskeeping and maintenance program is surface water management. A surface water management program is site-specific (i.e., dependent on each site's topography, amount of rainfall, etc.), but its overall purpose is to divert surface water resulting from precipitation away from open trenches and to allow the surface water to flow offsite in a manner which will minimize erosion.

3.6.3.5 Site Safety, Radiation and Contamination Control

A program of site safety, radiation and contamination control is carried out at the site in compliance with existing standards in 10 CFR Part 20. It consists of 4 major activities:

- personnel radiation monitoring, including use of personnel monitoring devices, periodic internal monitoring, and administrative controls to ensure radiological safety;
- site radiation and contamination control, including routine radiological surveys to minimize the potential for spread of contamination or unnecessary exposure to radiation;
- abnormal or emergency procedures to quickly and safely handle abnormal occurrences or site emergencies; and
- personnel training and instruction in the hazards and controls of radioactive materials commensurate with the workers's duties and responsibilities for handling materials, and with the extent of anticipated worker exposure.

Monitoring devices are worn by all site personnel who may become occupationally exposed to ionizing radiation. A long-term record of cumulative personnel exposures is maintained through the use of film or thermoluminescent dosimeter (TLD) badges. These are replaced, analyzed, and the resulting exposures reviewed and recorded on a periodic basis (usually on a monthly or quarterly schedule). Monitoring badges are replaced and analyzed whenever there is reason to believe that an employee may have received an unusually high radiation dose. Pocket dosimeters are also worn by site personnel and are used to provide an indication of radiation exposures over shorter time periods. These basic monitoring devices may, depending upon the circumstances, be supplemented by additional equipment such as electronic dose ratemeters, finger or wrist monitoring badges, or/and continuous air samplers.

3.6.3.6 Security

The site security program is needed both for radiation health and safety considerations as well as to protect the many thousands of dollars worth of equipment, buildings, and facilities located onsite. The security program at the base case facility is assumed to include the following:

- Full-time security personnel and a security training program;
- Controlled access and exit from site areas including fencing and lighting, material gate passes, badge control, personnel and vehicle search procedures, and lock and key control;
- Radio and telephone communication ability with emergency and law enforcement agencies;
- Identification badges and dosimetry for site employees and visitors; and
- Procedures for notifying site personnel and local authorities in the event of an emergency in compliance with federal and state regulations and conditions.

3.6.3.7 Recordkeeping and Reporting

A number of records are assumed to be maintained at the site to cover the areas required by NRC regulations, operational controls, and for future use. Records which are assumed to be maintained at the facility include:

- Personnel exposures;
- Waste receipt and disposal records;
- Personnel training records;
- Records from the QA program;
- Environmental monitoring data;
- Operating procedures; and
- Records of site surveillance and monitoring.

3.6.3.8 Quality Assurance

The quality assurance (QA) program at the site provides quality control and training support to the disposal site operations. The QA program includes the following areas:

- o personnel monitoring;
- o training;
- o emergency drills and equipment;
- o contamination control;
- o working procedures;
- o site maintenance;
- o site groundskeeping;
- o waste receipt, inspection, storage, and disposal;
- o radiation instrument care and calibration;
- o environmental monitoring;
- o security;
- o construction of disposal trenches;
- o closure and stabilization; and
- o recordkeeping

3.6.4 Facility Closure and Long-Term Site Control

Final closure is assumed to require approximately one to two years and involves dismantling and decontamination of site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring. The final disposal trenches are filled, capped, graded, and seeded with a grass cover. The trench covers are left mounded. The licensee also makes a final survey of the disposal area to make sure direct radiation levels are at essentially background levels.

Following closure, the disposal license is terminated and control of the site is transferred to the site owner. For this EIS, the site owner is assumed to be a state agency which carries out an active institutional control program of surveillance, monitoring and maintenance for 100 years. Activities which take place during the institutional control period include site inspection, maintenance and site monitoring. Due to the compressible nature of much of the wastes disposed of at the base case site and limited compaction during operations, a high degree of subsidence and slumping problems occur at the site. Base case site maintenance is, therefore, expected to be significant. The maintenance activities required during this time period mainly involve repair of slumping, subsidence and other disposal trench instability problems. During this phase, environmental surveillance and monitoring of the disposal facility continues.

3.6.5 Reference Disposal Facility Costs

Cost estimates for capital outlay, operational activities, and postoperational activities are provided in this section as a basis for comparison with the costs of alternatives. A summary of the three major components of the costs for reference facility capital outlay, operations, and postoperations are detailed in Table 3.6.

The capital outlay expended by the disposal company includes the costs of site selection, environmental impact studies, obtaining licenses and permits, the purchase price of the acquired land, road and building construction, engineering design fees, and peripheral systems such as fencing, lighting, and monitoring system components. The engineering design fees total 10 percent of the capital construction costs. The acquired 200 acres are assumed to be purchased at a price of \$1200/acre. The site buildings are constructed at costs ranging from \$10/ft^2 (storage shed) to \$50/ft^2 (waste activities building) with an average building cost of \$36/ft^2.

The operational costs include the cost of trench construction, equipment leasing, operation and maintenance costs for the equipment, payroll, and monitoring services. The elements of trench construction include excavation, sump and standpipe construction, French drain installation, backfilling, compacting, land clearing and grubbing, and revegetation (seeding and fertilizing). All equipment is assumed to be leased during the 20 years of operation. The annual payroll for this disposal company is \$1.13 million for the 70 employees. All radiochemical monitoring analyses are performed by a subcontractor and these costs are included in operations.

The cost of postoperational activities include closure, stabilization and long-term care. The closure and stabilization program for the reference site is similar to the "minimum plan" for the humid eastern site described in NUREG/CR-0570 (See Appendix Q). The minimum plan costs approximately \$1 million.

The institutional control or long-term care program for the reference site is carried out over a 100-year period and includes labor, material, and equipment costs. During the first (ten) years of the active insitutional control period, the annual costs of care are at their highest. As the site matures, the required costs diminish. The annual long-term costs for years zero through 10 (0-10), 11 through twenty-five (11-25), and twenty-six through one hundred (26-100) are \$440 thousand, \$302 thousand, and \$150 thousand, respectively. The types of activities which are carried out during the long-term care program

Table 3.6 Total Reference Site Costs

Direct Capital Costs (preconstruction and construction)	(1980$)
1. Site selection	500,000
2. Environmental impact studies	600,000
3. NRC licensing fees	325,000
4. Other licenses and permits	250,000
5. Land acquisition (200 acres @ $1200/acre)	240,000
6. Corporate administration	1,625,250
7. Construction administration	450,450
8. Legal fees	1,000,000
9. Road construction	200,000
10. Initial land preparation (40 acres @ $1145/acre)	45,800
11. Office and other miscellaneous equipment	400,000
12. Building construction	1,173,250
13. Utilities and supplies during construction	175,000
14. Peripheral systems (fencing, lighting, utilities installation, telephone, etc.	300,000
15. Engineering and design (10% of items 9, 12 and 14)	167,300
Total:	7,452,050
Indirect Capital Costs	**Percentage of Direct Costs**
Interest during construction	33%
Contingency	30%
Other Costs (insurance, sales tax)	10%
Total:	73%
Annual fixed capital charge rate for 20 years	25%
Assumed profit margin	20%

TOTAL CAPITAL COSTS

Direct costs x indirect costs x annual fixed charge x profit

$7,452,050 \times 1.73 \times 0.25 \times 20 \times 1.20 =$ 77,352,300

Table 3.6 (Continued)

Direct operational costs over 20 years	
1. Operations and maintenance	4,626,500
2. Disposal trench materials	124,200
3. Heavy equipment	12,228,000
4. Payroll:	
Base	22,560,000
Fringe	2,256,000
Overhead	12,408,000
5. Corporate administration (300k/yr)	6,000,000
6. Legal fees (150k/yr)	3,000,000
7. Environmental monitoring	534,000
8. Regulatory costs	1,138,000
9. Consumables (utilities, fuel, etc. - 200k/yr)	4,000,000
Total:	68,875,000
Indirect operational costs	30%
Assumed profit margin	20%
TOTAL OPERATIONAL COSTS	
Operational costs x indirect costs x profit 68,875,000 x 1.30 x 1.20 =	107,445,000
Postoperational Costs*	
1. Closure and stabilization (Cost over 20 years including inflation and surety)	3,640,000
3. Institutional Control - 100 Years	34,600,000
TOTAL POSTOPERATIONAL COSTS	38,240,000
TOTAL REFERENCE SITE COSTS	
Total Capital Costs plus Total Operational Costs plus Total Postoperational Costs	223,037,300
UNIT DISPOSAL COSTS	
Total reference site costs (223,037,300) / Total volume of waste over 20 year operation period (10^6 m^3) =	223/m^3 (\$6.31/ft^3)

*Postoperational costs have been calculated based on a 9% inflation rate and 10% interest rate to reflect the actual costs to customers in 1980.

include erosion repair, vegetation management, subsidence repair, site access and drainage maintenance, surveillance and monitoring.

3.7 ALTERNATIVE WASTE DISPOSAL OPTIONS

NRC also analyzed a range in site characteristics and methods of design and operation that could be applied in the near-surface disposal of LLW. Some of the variations included differences in environmental and site parameters. Others included the specific methods used for the design and construction of the disposal facility including the method of disposal (e.g., trench with natural soil walls, trench with concrete walls), type of cover (e.g., soil, concrete) and whether special engineering designs were used for the disposal of particular wastes (e.g., slit trenches, caissons and tubes filled with concrete). Others included the procedures used for operation and placement of the waste including whether the waste was randomly dumped or neatly stacked, segregation of particular wastes due to unique characteristics, type of backfill, and stabilization and closure measures. Other aspects that also had to be considered were how much care a particular disposal facility might require after closure, and how long active institutional controls would be in effect at the facility.

3.7.1 Grouping of Alternatives

NRC generalized the various parameters which could be grouped to describe alternative site environments, methods of design, operation and closure, and postoperational institutional control activities into 13 categories as follows:

1. Region - The region specifies the geographic location of the disposal facility. (e.g., northeast, southeast) and as such determines all of the environmental properties that will be used in the analysis. Four regions were selected (Northeast, Southeast, Midwest, and West) Environmental properties common to each were selected for use in the analyses.

2. Design - Two principal design options are considered; use of a "regular" trench dug in the soil and use of a concrete walled trench.

3. Cover - Three principal cover designs are considered: thin, denoted by 1 meter of cover below grade and 1 meter of cover above grade; thick, denoted by 1 meter of cover below grade and 2 meters of compacted clay cover above grade, and intruder barrier, denoted by a 5-meter thick above grade highly engineered cover.

4. Emplacement Method - Three emplacement alternatives are considered:

   - Random, which simply involves dumping the waste directly into the disposal cell (a subset of this case is use of a highly permeable backfill);

   - Stacked, which involves stacking waste containers in neat piles (again, a subset of this case is use of a highly permeable backfill); and

- o Decontainerized which involves removing wastes from containers before disposal. In this case, structurally stable wastes in containers are randomly disposed and other low activity structurally unstable wastes are removed from their containers for disposal.

5. Layering - Layering involves the placement of selected higher activity waste streams on the bottom of disposal cells.

6. Segregation - Segregation involves the segregation and disposal in separate disposal cells of compressible wastes and those containing organic chemicals or radionuclide complexing chemicals.

7. Grouting - Grouting involves the use of concrete as a backfill material in place of natural soil.

8. Hot Waste Facility - A hot waste facility is a specialized disposal cell that would be used for higher activity wastes.

9. Stabilization - Stabilization denotes the extent to which disposal units are stabilized during operations, and during and after closure.

Three stabilization measures are considered:

- o A program in which no special compaction procedures are used except for the weight of heavy equipment;
- o A program in which improved compaction techniques such as sheepsfoot rollers and vibratory compaction are used; and
- o A program involving dynamic compaction or similar extreme measures.

10. Closure - Two types of actions implemented during the closure period are considered. One involves the application of standard practices such as dismantlement and decontamination of site buildings, disposal of any wastes generated, final contouring of the site, revegetation, final radiation surveys and other actions as set out in the NRC Branch Technical Position on Site Closure and Stabilization. The second involves the application of more extreme measures (in addition to the regular measure discussed above) including stripping of disposal unit covers, compaction using sheepsfoot rollers or similar measures, backfilling, recovering and revegetation of covers.

11. Care Level - Care level refers to the amount of active maintenance that will have to be carried out during the active institutional control period based on the design and operational procedures used at the facility. Three levels of care are considered:

- o Routine surveillance and minor maintenance;

- o Routine surveillance with some active maintenance such as periodic cover restabilization; and

- o Major stabilization and remedial actions such as active trench pumping and leachate treatment programs.

12. Postoperational Period - The postoperational period denotes the time between cessation of active disposal operation to assumption of control by the site owner. It includes the time required to close the site and any period of observation before assumption of control by the site owner.

13. Active Institutional Control Period - This period is the time between transfer of control of the site to the site owner and the time at which institutional controls are assumed to cease.

3.7.2 Impact Measures

Impact measures calculated by NRC for the disposal of waste include the costs for the design and operation of the disposal facility including a fixed return on investment; costs to close the facility and to care for it over the long term; energy use; land use and commitment; occupational exposures; and exposures to individuals and populations due to inadvertent contact with the disposed waste at a future time and due to long-term releases to the environment. These are discussed in further detail below.

3.8 IMPACT MEASURES USED AND METHOD OF CALCULATIONS

Impact measures can be grouped into two categories:

1. Benefits, consisting, for example, of the value of goods and services produced through the utilization of radioactive material that results in generation of the waste or the reduction in health and environmental hazards presented by the waste through application of a specific disposal technique; and

2. Costs, consisting for example, of the costs to dispose of the waste and the potential environmental and human health hazards created by the LLW.

Direct benefits to society from the generation of LLW are the value of the goods and services produced through the utilization of radioactive materials and include monetary and nonmonetary benefits. These goods and services encompass a wide range from consumer products (e.g., luminous wrist watches and smoke detectors) and energy (e.g., electricity from nuclear power plants) to less economically measureable goods (advances in scientific research activities) and services (health benefits from nuclear medicine procedures). Other benefits associated with the use of radioactive material would include the salaries of persons employed in the nuclear or radioisotope industry, and local and regional socioeconomic benefits such as an increased tax base. Benefits to society and the natural environment derived from those involved in the disposal of waste and the regulation of these activities are the provision of goods and services for the safe disposal of radioactive waste and the reduction in potential environmental and human health hazards.

Direct costs to society would be the creation of the LLW and its attendant potential environmental and human health hazards and the short- and long-term financial, governmental, human and natural resources used to properly dispose of the waste. Persons will be exposed to the waste as it is being transported and after disposal through potential releases from the site. At any specific disposal site, the local ground water, biota and animal species will be affected by site operation. And, fuel will be consumed in transporting the waste to a disposal site and in powering equipment at the site involved in site operations. Finally, the cost for disposal of the waste will be reflected in the cost for goods and services provided by those generating the waste.

Thus, it is quite difficult to accurately assess the cost and benefit impacts on the many segments of the environment involved because many are nonmonetary (e.g., improved well-being due to improved diagnosis through nuclear medicine) and in many cases a small part of a much larger overall cost (e.g., that portion of electrical usage charges attributed to the disposal of LLW). It is equally difficult to quantify the impacts of application of the rule on the physical and local socioeconomic environment (e.g., ground water, ecology, local taxes) since the impacts can only be analyzed based upon a specific real site. Finally, given the rather large and diverse nature of the affected environment, a rather large number of potential factors can be identified which could be used to quantify environmental impacts. In this EIS, NRC has attempted to identify important segments of the environment (both direct and indirect) that lend themselves well to generic treatment, that can be easily quantified based upon existing information, and which provide a reasonable measure of the short- and long-term potential impacts that could be expected from implementation of a specific alternative course of action that might be set out as a requirement in the new regulation.

3.8.1 Impact Measures Used

NRC's overall goal is to assure protection of the public health and safety and environment. In considering radioactive waste disposal, this goal falls into two time frames: (1) protection of workers and the public during the short-term operational phase and, (2) protection of the public health and safety over the long term after operations cease. Each of the existing disposal sites was licensed on a case-by-case basis. As with other nuclear facilities, emphasis was placed on protection of the public health and safety focusing principally on operational safety and radioactivity releases and exposure of offsite individuals and populations. There was a tendency to focus on operational safety at the disposal sites with, perhaps, less attention given to the long-term performance of the disposal facility. Disposal facilities involve some quite different considerations than those applied to other nuclear facilities. At the end of their operating life, (e.g., 40 years) other nuclear facilities are decommissioned, decontaminated and released for unrestricted use. Disposal facilities, however, although involving considerations of safety during its relatively short operating life (e.g., 20-40 years), are relied upon for significantly longer periods of time (e.g., several hundred years after waste emplacement) to perform their function of confining waste with reasonable assurance over the time the waste presents a significant potential hazard to the public health and safety.

Thus, safety must be assured during the short-term operational phase relating to onsite occupational exposures and exposure to individuals and populations offsite as well as over the long term relating to exposures to individuals and populations.

In addition, the long-term social commitment must be considered. For example, maintenance operations at some existing sites require an expenditure of manpower and money to maintain the site and to minimize impacts from potential offsite releases. Such "active" maintenance operations involve additional expenditures which were not foreseen nor planned at the time that the disposal facility was opened. They involve long-term social commitment in terms of manpower and money that was not planned for and which is difficult to assess in terms of how long such programs must be relied on to assure continued safety of the site. The function of an LLW disposal facility should be to assure that the public health and safety is protected without the need for long-term social commitment in the form of "active" maintenance programs at the sites.

Long-term social commitment is also important when considering future use of a disposal facility and intrusion. For example, governmental entities can continue to exercise active institutional control over a disposal facility after closure (i.e., continue to actively and physically control access to the site) for an indefinite time after closure. How long, however, should such controls last? If they last indefinitely, the long-term costs and social commitment of future generations would be very high. If they were not relied upon at all, the costs for disposal of low activity wastes would be very high. Thus, consideration of long-term social commitment is important such that institutional controls applied at a disposal facility are sufficiently long to allow most wastes to decay to acceptable levels yet not so long as to burden future generations.

Given the short- and long-term safety considerations, the potential exposure modes and need to consider social commitment, there are four basic performance objectives that should be achieved in the disposal of LLW:

1. Long-term protection of the intruder considering the need for long-term social commitment;

2. Long-term protection of the public from potential releases to the environment considering the need for long-term social commitment;

3. Short-term protection of workers and the public while the site is in operation; and

4. Long-term stability and elimination of the need for active maintenance.

The first two objectives point out the need for long-term stability and predictability in disposal facility performance as well as consideration of long-term social commitment. Potential long-term releases to the environment and potential exposure of an intruder should be accomplished in such a manner that major social commitment is not required and no undue burdens are placed on future generations. These, at the same time, need to be balanced with the costs for disposal to be borne by present generations based on a range of alternative approaches that can be followed to improve safety in disposal. Thus, the method of calculation developed and applied by NRC in this EIS calculates both short-term impacts that occur at the point of generation, during transport, and during disposal operations; and the long-term impacts that occur after the disposal facility closes. These can be divided into several impact evaluation factors as follows:

1. Short-term costs to a waste generator for processing, packaging, transport and disposal of the waste;

2. Short-term radiological impacts (occupational and public exposures) due to processing, packaging, transport, and disposal of waste;

3. Long-term costs to care for the site over the long term after operations cease;

4. Long-term radiological impacts (public exposures) due to disposal of the waste;

5. Energy consumed during processing, transport and disposal of the waste; and

6. Land committed for the disposal of waste.

Other potential impact measures such as man-hours expended and material requirements (e.g., clay, gravel, concrete, etc.) are implicitly included in the above measures. NRC also assumed that no land is permanently committed during waste processing and transportation activities. These impact measures can be grouped by the three principal phases of waste disposal discussed earlier, namely:

Waste Processing	Waste Transportation	Waste Disposal
Costs ($) Occupational exposures (man-mrem) Fuel use (gallons of fuel) Population exposures (man-mrem)	Costs ($) Occupational exposures (man-mrem) Fuel use (gallons of fuel) Population exposures (man-mrem)	Costs ($) Occupational exposures (man-mrem) Fuel use (gallons of fuel) Exposure to individuals and populations (mrem and man-mrem) Land use (m^2)

Each of these are discussed in further detail below as a part of the description of the method of calculation used.

3.8.2 Method of Calculation

The various ways that a person can be exposed to radioactive waste may be divided into three principal categories:

1. Activities involving the processing and handling of the waste prior to disposal. This would include activities involved in the handling, processing, and packaging of the waste at its point of generation; transport of the waste from the point of generation to disposal; and activities at the disposal facility involving emplacement of the waste at the disposal facility (processing of waste at facilities other than the generating licensee's facility would also be included).

2. Man contacting the waste after disposal (i.e., intrusion into the disposal facility leading to exposure to disposed waste). This would include activities of man that would lead to his intruding into the disposal facility either purposefully (such as an archeologist in the future intentionally digging into the sites attempting to reclaim artifacts from the disposed waste) or inadvertently (such as an unknowing individual who might attempt to use the land for reasonable productive purposes in the future--e.g., farming or housing).

3. The waste entering one of several natural environmental pathways back to man (e.g., migration). This would include the potential leaching and transport of the waste through the ground water; intrusion and dispersion by plants and animals; long-term erosion of the site with eventual uncovering of the waste and surface water and air transport; and release of gaseous decomposition products from the waste containing radioactive species (e.g., tritiated methane gas).

The first mode involves primarily short-term considerations and the second and third, long-term considerations.

3.8.3 Waste Generation/Processing

Short-term impacts calculated at the point of waste generation include occupational exposures, population exposures, costs, and energy use. The impacts due to processing of the waste are described in this section. The occupational exposures involved with the handling of the waste during loading are described in the following section regarding transportation.

Waste processing options analyzed were divided into volume reduction processes such as compaction, evaporation and incineration; and volume increasing techniques such as solidification, addition of absorbent material and packaging.

NRC assumed that only incineration would result in the release of significant quantities of radioactivity to the environment and population exposures were calculated based upon fractional release rates for small (pathological) and large (fluidized bed) incineratiors; whether the processing was done at the point of generation or at a central facility; and the local environment. Institutional facilities were assumed to be located in an urban environment and all others in a rural environment. Occupational exposures were calculated based upon the person-hours required to process the waste and the radiation field associated with the general work environment.

The amount of energy required to process the waste was also determined and is expressed in units of gallons of fuel consumed. Labor hours and costs for processing were also determined based upon published data.

The unit rates for costs, energy use, and labor hours assumed for the processes considered in this EIS, compaction, evaporation, incineration and solidification are summarized in Table 3.7.

Table 3.7 Summary of Processing Unit Impact Rates

Process	Cost (1980 $)	Labor (hours)	Energy (g of fuel)	Units
Compaction				
Regular	335	15	4.6	Per m^3 of Input
Improved	503	15	4.6	
Hydraulic Press	1,006	15	4.6	
Evaporation	690	4.42	56.3	Per m^3 of Input
Incineration				
Pathological	2,060	8	116	Per m^3 of Input
Fluidized Bed (small)	1,938	6.12	1.29	
Fluidized Bed (large)	1,039	5.35	72	
Solidification				
Scenario A	1,200	17	47	Per m^3 of Output
Scenario B	1,700	14	39	
Scenario C	1,900	12	33	

3.8.4 Waste Transportation

Impacts calculated during transportation of the waste include occupational exposures, population exposures, energy use and cost. Also included in this subsection because of similarities are the occupational exposures incurred during handling of the waste at the point of generation and at the disposal facility.

The occupational and population exposures incurred during transportation are calculated based on total loaded miles travelled and the number of loaded shipments (i.e., return trips when the vehicle is empty are excluded). The exposure rates used for occupational and population exposures incurred during transportation are summarized below:

	Population Doses (person-mrem)	Occupational Doses (person-mrem)
During transit per shipment mile	0.018	0.02
During stopover per shipment	2.0	2.0

The occupational exposure resulting from handling of the waste at the point of waste generation were calculated based on the man-minutes required to load each container and the radiation field associated with the level of care required to handle the container. Occupational exposures were also calculated for the handling of waste at the disposal facility during disposal based on the personnel time required for unloading and disposal and the radiation fields associated with the handling environment that the workers are exposed to.

Other impact measures calculated involved costs for transportation which include a mileage charge, fuel surcharge, cask use rental charge and the energy use calculated based on the total shipment miles traveled assuming an average fuel consumption rate of 6 miles per gallon.

3.8.5 Waste Disposal

Impacts calculated at the point of disposal include occupational exposures, population and individual exposures, costs for disposal, costs for long-term care, energy use and land use.

The calculation of land committed for waste disposal is based on the volume of waste disposal of, the method of waste emplacement and the particular design of the disposal facility.

Waste disposal costs may be divided into two types of costs--design and operation costs, and postoperational costs. Design and operation costs represent fees charged by the disposal facility operator to cover design and operation of the disposal facility, and to receive a fixed return on investment. These include capital costs (costs associated with siting, designing, licensing, and initial construction of the disposal facility) and operational costs (costs associated with receipt and disposal of waste, as well as construction of disposal cells).

Postoperational costs include costs for (1) facility closure, and (2) long-term care by the site owner. Included in the postoperational costs are costs associated with acquisition by the licensee of surety bonds, letters of credit, or other financial instruments which are used to provide assurance to the site owner that funding for closure and long-term care will be available.

Occupational exposures are calculated in two phases: the exposures to waste handlers who unload and dispose of the waste (discussed in the preceeding section) and occupational exposure of other site personnel performing routine operational and administrative functions not directly connected with waste handling. Occupational exposures, costs and energy consumption are related to the volume of waste disposed of, operational practices, and the design of the facility. Unit impact measures were calculated for the base case facility described in Appendix E and for the variations described in Appendix F. They are summarized in Table 3.8. The specific exposure pathways analyzed regarding disposal of the waste and the short- and long-term radiological impacts, and other costs of disposal are discussed in detail in Chapters 4, 5 and 6. Chapter 4 addresses exposure of an intruder, Chapter 5 addresses long-term environmental releases, and Chapter 6 addresses short-term releases during operations and processing of waste at a centralized regional processing facility.

The methodology calculates:

- o the occupational exposures and the exposures to the members of the public (individuals and population) resulting from the disposal of LLW;
- o the occupational and the population exposures resulting from the processing of the waste by the waste generators or by the operators of a centralized regional processing facility (assumed to be at the disposal site), and the transportation of the waste from the waste generators to the disposal site;
- o the costs and the energy use associated with processing, transportation, and disposal of LLW; and
- o the land area committed to disposal of LLW.

For waste processing purposes, population doses are limited to exposures due to airborne releases from waste incineration or calcination. For waste disposal, the calculational methodology determines the following exposures:

- o Ground-water migration
  - To an individual (an intruder) from a well located on the disposal facility following the end of the active institutional control period.
  - To an individual from a well located at the disposal facility site boundary.

Table 3.8 Unit Rates for Impact Measures

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
<u>Preoperational</u>				
Reference Base Case	7,452	--	212	Lump Sum
Additive Alternatives†				
Walled Trench	594	--	--	Lump Sum
Stacking	226	--	--	Lump Sum
Segregation	1	--	--	Lump Sum
Layering	132	--	--	Lump Sum
Decontainerized Disposal	924	--	--	Lump Sum
Hot Waste Facility	260	--	--	Lump Sum
Grouting	55	--	--	Lump Sum
Intruder Barrier	281	--	--	Lump Sum
Extreme Stabilization	10	--	--	Lump Sum
<u>Operational</u>				
Reference Base Case				
Trench (-Cover)	2,341	300	200	Disposal Vol.
Regular Cover	1,420	2,400	100	Disposal Area
Other	63,696	1,000	200	Lump Sum
Additive Alternatives†				
Walled Trench	74,438	700	300	Disposal Vol.
Stacking	12,758	100	100	Total Waste Vol.
Segregation	3,888	100	30	Total Waste Vol.
Layering	15,400	-100	30	Vol. Disp. by Layer
Decontainerized Disposal	48,975	400	100	Vol. Disp. by Decon
Hot Waste Facility	176,979	-200	450	Vol. Disp. by HWF
Grouting	72,405	2,550	800	Grout Volume
Sand Backfill	3,270	--	185	Sand Volume
Cover Options				
Thick	15,524	2,400	150	Disposal Area
Intruder Barrier	103,854	2,400	300	Disposal Area
Moderate Stabilization	3,465	4,800	300	Disposal Area
Extreme Stabilization	33,345	4,800	600	Disposal Area

Table 3.8 (continued)

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
Postoperational				
Closure Period				
Regular Closure	1,010	500††	15	Lump Sum
Extensive Closure	3,025	1,000	60	Lump Sum
Institutional Period#				
Low Care Level				
Years 1-10	150	--	2	Per Year
Years 11-25	63	--	2	Per Year
Years 26-100	51	--	2	Per Year
Medium Care Level				
Years 1-10	303	--	6	Per Year
Years 11-25	150	--	6	Per Year
Years 26-100	63	--	6	Per Year
High Care Level				
Years 1-10	440##	--	10	Per Year
Years 11-25	303	--	10	Per Year
Years 26-100	150	--	10	Per Year

*Occupational exposures associated with operations other than waste unloading and disposal.

**Lump sum items are assumed to be independent of the waste volume. Disposal volume dependency is for 1 million m^3 of disposal (not waste) volume; grout volume dependency is for 1 million m^3 of grout injected; sand volume dependency is for 1 million m^3 of sand backfill; disposal area dependency is for 1 million m^2 of trench cover area.

†Rates for alternatives are incremental rates in addition to the rates given for the reference system.

††Regular closure assumed to last 2 years, extensive closure is assumed to last four years. Both cases assume 5000 person-hours of field work per year in an average radiation field of 0.05 mR/hr.

#These costs are basic costs not considering inflation or interest. Details for complete calculation of the institutional period costs can be found in Appendix Q. The formulae given in Appendix Q are incorporated into the cost calculation procedure.

##To this cost, a contingency cost is added which depends on the soil conditions: $367,000 for medium-permeability soils; $168,000 for high-permeability soils; and, $1,007,000 for low-permeability soils.

  - To a small population consuming water from a well located halfway between the facility and the hydrologic boundary (a steam).

  - To a small population consuming water from the hydrologic boundary.

- Exposures to an inadvertent intruder or small group of intruders who at some point in the future may potentially:

  - Construct a house on the site, or

  - Live in the house and consume food grown on the site in contaminated soil.

- Exposures to a small population from:

  - Airborne transport of radionuclides due to uncovering of the disposed waste by either a potential intruder or through erosion; or

  - Waterborne transport of radionuclides due to uncovering of the disposed waste by either an intruder or through erosion.

- Exposures to individuals located offsite through airborne release of radionuclides due to an operational accident such as a dropped container or a fire.

The details on development and application of the calculational methodology are set out in Appendices G, H and Q.

Chapter 4

PRESENTATION AND ANALYSIS OF ALTERNATIVES-INTRUDER

4.1 INTRODUCTION

This chapter reviews the potential hazard presented by inadvertent human intrusion into disposed waste and methods which may be used to mitigate the hazard. Two general concentration-limited inadvertent intrusion scenarios are considered:

1. Excavation into disposed waste or construction of a house or building at the disposal facility; and

2. Living on and consuming food grown at the disposal facility.

As implied above, the first general intrusion scenario may be broken into two sub-scenarios, depending upon the length of time that exposure occurs.

A third inadvertent intrusion scenario, which involves consumption of water from a well drilled at the site, is considered in Chapter 5 since it relates to ground-water migration.

Four methods are addressed by which potential human intrusion impacts may be mitigated:

1. Controlling the disposal of specific waste streams;

2. Waste form and packaging;

3. Institutional controls; and

4. Use of engineered and/or natural barriers to intrusion.

Section 2 presents background information about intrusion and selection of the specific scenarios analyzed in this EIS. Section 3 analyzes inadvertent human intrusion presenting the impacts of the base case "no action" alternative and incremental changes in those impacts due to application of a range of alternative controls involving disposal of specific waste streams, waste form and packaging, institutional controls, and use of natural and engineered barriers. Sections 4 and 5 analyze development of a performance objective for protection of an inadvertent intruder leading to selection of a preferred performance objective. Section 6 reviews technical requirements derived from the analyses, and those involving codification of existing practice, that should be applied in the near-surface disposal of waste to ensure protection of the inadvertent intruder. For those requirements involving a change to existing practice, a range of alternatives is considered and the costs and impacts presented. In some cases, based on a balancing of costs and benefits, a specific prescriptive requirement is selected. In other cases, flexibility in meeting the requirement is maintained to allow for individual cost-benefit considerations.

4.2 BACKGROUND INFORMATION ON HUMAN INTRUSION

In determining performance objectives and technical criteria for near-surface radioactive waste disposal, one of the considerations is the potential for human intrusion into the disposed waste. That is, at some time after the disposal facility is closed, an individual or group of individuals may perform such activities as excavating through the disposal cell covers and into the disposed waste.

It is recognized that the possibility of human intrusion into a closed near-surface disposal facility is only hypothetical. Existing regulations require that near-surface disposal facilities be sited on land owned and under the control of either the federal government or the government of the state in which the facility is located. As part of this "institutional control," the site owner would restrict the types of activities that would be carried out at the facility. For example, the closed facility may be fenced and maintained under periodic surveillance. As another example, an individual or a corporation may be licensed by the state or federal government to carry out productive surface activities on the facility, with the provision that the licensee does not excavate into the disposed waste.

The concern is that at some time after the facility is closed, institutional controls may break down and an intrusion event may occur. The one or few individuals intruding into the facility would then be exposed, through direct contact, to any waste disturbed through the intrusion event. Such intrusion may also act to increase the potential for ground-water migration by increasing the infiltration of precipitation into the waste and it may also bring wastes to the surface where they may potentially be dispersed by wind or water. These actions may result in radiation doses to the surrounding population. However, the largest radiation exposures by far would be to the individual intruders themselves.

Given the potential for human intrusion and the possibility of human exposures from intrusion, NRC believes it is reasonable to estimate the magnitude of exposures that could be received by an intruder. If such potential exposures appear to be significant, then it would be reasonable to explore ways in which such potential exposures can be reduced. First, however, some estimate should be made of the types of activities that could be potentially carried out by an intruder and of the potential pathways for exposure.

4.2.1 Human Intrusion Exposure Pathways

Intrusion into disposed waste may be either deliberate or inadvertent. A deliberate intrusion event implies that the intruder knows of the potential hazard of the disposed waste but for some reason deliberately chooses to ignore the hazard. For example, the intruder could be seeking something of potential value in the disposed waste. This would appear to be an unlikely scenario, however. The disposal facility would be under the surveillance and control of the government and deliberate intrusion into the waste to try and retrieve something of value would be a criminal act. Therefore, in order to deliberate intrusion

preclude discovery, the intruder would want to perform his activities as quickly as possible. In addition, if it is assumed that the intruder chooses to deliberately ignore a known potential radiation hazard, then it must also be assumed that the intruder would want to minimize his potential exposures by minimizing the time spent in contact with the waste. However, intrusion would involve digging through a few meters (e.g., 2 to 4) of soil prior to contacting the waste, which would take time. Power machinery would probably be needed to excavate soil and waste packages, which would make the assumed intrusion event rather conspicuous. In addition, the intruder would not have any knowledge regarding where a potentially valuable article might be. This means that the intruder would have to spend a considerable amount of time in a hazardous environment in order to find something of possible value during which the chance of discovery would be great (and would increase the longer the time spent) and the potential profit small. If would therefore appear that intentional intrusion after something of value would not be a profitable undertaking, and most people would not take the risk. In any case, it would appear to be difficult to establish regulations designed to protect a future individual who recognizes a hazard but then chooses to ignore the hazard.

On the other hand, inadvertent intrusion implies that an individual or group of individuals intrude into the waste either accidently or without realizing that there is a potential hazard. The former case appears to be the most likely. For example, a person who is licensed to maintain the facility might have some reason to excavate on the facility ground (e.g., to install a monitoring device) and could possibly misjudge the locations of the disposal cells and accidently dig into disposed waste. In this case, the hazard would be immediately recognized (certainly within a few minutes) and minimal exposures would result. (It must be assumed that individuals licensed to maintain the facility would have a knowledge of radiation safety and would at least be equipped with radiation detection equipment such as survey meters and would know how to use them.)

More significant exposures could occur if the intruder does not realize at first that there is a potential hazard. This could occur if there is a breakdown in institutional controls and the site owner mistakenly releases the facility for unrestricted use. (This, however, is unlikely as discussed in Section 4.3.6.) Assuming that such a thing occurs, then there are many possible scenarios for human exposure. A rather extreme scenario would be one in which the waste is contacted for extended periods of time.

The potential for inadvertent intrusion into a closed waste disposal facility assuming a breakdown in institutional controls has been examined in detail in studies by a number of investigators, including Lawrence Livermore Laboratory (Ref. 1), Ford, Bacon, and Davis, Utah (Refs. 2, 3), the Utility Waste Management Group (Ref. 4), and the Department of Energy (Ref. 5). A summary of the scenarios examined by these investigators are listed in Table 4.1. All of the studies were performed as part of efforts to classify radioactive wastes for disposal.

As can be seen, the studies investigated a number of scenarios in which a potential inadvertent intruder could be exposed, including construction of

Table 4.1 Comparison of Intruder Exposure Scenarios

Ford, Bacon and Davis (Ref. 2 3)	Department of Energy** (Ref. 5)	Utility Waste Management Group (Ref. 4)
(1) Inhalation of contaminated dust from construction activities*	(1) Sheet erosion of waste into a stream, followed by either:† o consumption of contaminated H_2O; o use of water for irrigation; or o consumption of fish obtained from the stream	(1) Leaching of waste into a water course
(2) Inhalation of contaminated dust by someone living on the disposal facility	(2) Ground-water migration of radionuclides to an aquifer, followed by either:† o consumption of contaminated H_2O;or o use of water for irrigation	(2) Spillage of waste on the ground, which is carried into a water course
(3) Consumption of contaminated water from an onsite well	(3) Retrieval of useful items by an artifact hunter	(3) Inhalation of spilled waste
(4) Consumption of food grown on contaminated soil*	(4) Exposure of waste, followed by persons living on the disposal facility being exposed through inhalation of contaminated dust and consumption of food grown on contaminated soil*	(4) Inhalation of dust during excavation by an intruder
(5) Direct gamma radiation exposure to a construction worker*		(5) Consumption of contaminated dirt by child
(6) Ground-water transport of radionuclides to a river		(6) Consumption of food grown in contaminated soil
(7) Sheet erosion of waste to a river		(7) Erosion of waste into water course
		(8) Inhalation of eroded waste
		(9) Direct gamma irradiation from 55-gallon drums
		(10) Direct gamma irradiation from the ground surface

*Determined by the authors to be generally controlling.

**The authors also reviewed, but did not treat in detail, other pathways including movement of waste to the surface by plant (nonfood) uptake, movement of waste to the surface by burrowing animals, and severe events, such as flooding, meteor impact, or glacial action.

†Whichever subpathway is most restrictive.

houses on top of a disposal facility, consumption of food grown in contaminated soil, and consumption of water from a well drilled into the disposal facility. Although a number of scenarios were investigated, all scenarios were composed of only three pathways of human exposure--i.e., inhalation of radionuclides, consumption of radionuclides through water or food, and direct gamma exposure. The pathways were used singly or in combination to determine impacts. One researcher examined the potential impacts of someone (a child) eating contaminated soil directly (Ref. 4). Another researcher examined the potential impacts from someone potentially retrieving an artifact contaminated with transuranic radionuclides from a disposal facility and using the artifact for his own purposes (Ref. 5). (Inhalation exposures are assumed to occur either while excavating or while the artifact hunter polishes the artifact.)

To calculate impacts (concentration limits for disposal) all investigators assumed that intrusion events take place some hundreds of years following waste disposal, after institutional controls cease. That is, for the first few hundred years following waste disposal, the disposal facility is assumed to be under the control of a government agency which precludes inappropriate use of the disposal facility. Following this time, the institutional controls are assumed to become ineffective and persons are assumed to be allowed to intrude into the disposed waste mass and carry out such typical activities as construction of houses or living on the facility. The most restrictive of the scenarios (the scenario leading to the highest exposures) is then used to determine limiting concentrations for disposal of waste by the disposal methods investigated.

In general, scenarios such as consumption of food, inhalation of dust, or direct gamma exposure were found in these studies to be more restrictive than scenarios involving contaminated ground water. The former types of scenarios may be termed "concentration-limited" scenarios. That is, to calculate impacts from such scenarios as inhalation of dust or consumption of food grown in contaminated soil, one is interested in the concentration of the radionuclides in which the activity takes place. The radionuclide concentrations or the total activity contained elsewhere in the disposal facility does not enter into the calculation. On the other hand, ground-water scenarios are "activity-limited" and the impacts depend upon the total activity contained in the facility and not especially on the concentration of radionuclides in any particular portion of the disposal facility. In addition, although the impacts from the concentration-limited scenarios are site-specific to a degree, they are much less site-specific than the activity-limited scenarios.

This implies that the concentration-limited scenarios may be a useful way to classify wastes in a relatively nonsite-specific manner. Intrusion is a hypothetical event, but the potential impacts represent a kind of "hazard index" with which to rank the potential "hazard" of different waste streams or to classify waste for disposal.

In addition, the previous investigators generally did not make allowances for waste form. It was generally assumed that the waste/soil mixture was indistinguishable from dirt. That is, the waste/soil mixture dispersed into the air in a similar manner as dust from bare soil. Root uptake into plants for human consumption was calculated assuming that the radionuclides essentially existed in a dissolved state in soil. The radionuclides were readily available for uptake by plant roots. One investigator did, however, investigate possible limits for activated or surface-contaminated metals (Ref. 2). Another investigator intrinsically considered waste form as part of his consideration of impacts to a potential future archeologist or artifact hunter (Ref. 5).

4.2.2 Intrusion Pathways Considered in the EIS

Given the above discussion, there may be a number of scenarios by which a potential intruder could be exposed to radiation. These scenarios range from potentially trivial events to events which could cause relatively significant exposures, and each scenario may have a finite probability of occurrence associated with it. Given this potential for significant intruder exposures, additional analysis is indicated in this environmental impact statement of methods which may be used to mitigate these exposures. However, to perform this analysis some preliminary decisons must be made on how the analysis is to be performed. There are two basic alternatives:

1. Devise a number of scenarios from the likeliest to the unlikeliest, assign each a fixed probability, and perform a risk analysis of the impacts; and

2. Determine a limited number of the most restrictive (high consequence) scenarios, assume the event occurs, and perform a consequence analysis of the impacts.

Neither of these two alternatives is totally satisfactory. For the first alternative, there may be any number of potential scenarios which could be invented, including minor variations. It would be impossible to consider all of these scenarios. In addition, it would be extremely difficult if not impossible to determine and assign numerical probabilities. Inadvertent intrusion is a hypothetical event that may or may not occur in the future. Given this uncertainty, it appears that a better approach would be alternative 2. This is the general approach followed by the previous investigators on waste classification. However, this also has its drawbacks. If extremely conservative, yet clearly unlikely scenarios are used, then the calculated results (which may involve conservatisms multiplied by conservatisms) can quickly become unrealistic and overly restrictive. This is especially important considering the hypothetical nature of the intrusion event.

NRC has, therefore, adopted a somewhat combined approach for numerical analysis. A limited number of intrusion scenarios are conservatively assumed to occur based upon consideration of typical human activities. The potential consequences are then calculated. However, given the hypothetical nature of the scenarios, once the intrusion scenario occurs, reasonably conservative actions on the part of the intruders are assumed to occur. In addition, some judgment is made as to the likelihood and extent of the scenarios occurring depending upon specific waste forms and disposal practices.

The intrusion scenarios considered in this environmental impact statement were developed based upon consideration of the work performed on waste classification by the above investigators. Two concentration-limited scenarios are considered as well as one activity-limited scenario. The concentration limited scenarios analyzed in the following subsections include (1) excavation into disposed waste or construction of a house or building upon the disposal facility and (2) persons living on the disposal facility. The activity-limited scenario analyzed involves potential use of contaminated water from a well drilled onsite. This scenario is analyzed in Chapter 5 as part of the ground-water migration analysis. Potential population exposures from radioactive material dispersed by intruders is also analyzed. All three scenarios are assumed to occur after institutional controls are assumed to be temporarily lost.

All scenarios are believed to be conservative and are discussed in detail in Appendix G.

4.2.2.1 Intruder-Construction Scenario

This scenario involves the assumed construction of a house directly into the disposed waste, and is referred to as the intruder-construction scenario. During construction activities, some of the waste is assumed to be contacted by the workmen (this could happen, for example, through construction of a basement). During construction, some of the waste is assumed to be dispersed into the air and onto the immediate area around the house. Exposures would principally occur through such pathways as inhalation of contaminated dust and exposure to direct gamma radiation from standing on contaminated soil and being immersed in a contaminated dust cloud. (A subset of this scenario called the intruder-discovery scenario, and involving reduced relative impacts, is discussed in Section 4.3.4.3.)

4.2.2.2 Intruder-Agriculture Scenario

The second scenario involves a potential situation in which an individual or individuals live in the house thus constructed. In addition to the exposure pathways for the construction case, the potential intruder could be exposed through consumption of food grown in the contaminated soil. (Consumption of water by the intruder from a well drilled at the site is analyzed in Chapter 5.) The length of time that the individuals would spend in the contaminated area would be greater for this scenario than for the intruder-construction scenario. This scenario is referred to as the intruder-agriculture scenario.

4.2.2.3 Population Exposures from Intrusion Activities

In this scenario, the waste which is uncovered and brought to the surface through inadvertent intrusion is transported offsite by surface water and wind. Exposures are calculated to the surrounding population.

4.3 DESCRIPTION AND IMPACTS OF BASE CASE (NO ACTION) AND OTHER ALTERNATIVES

4.3.1 Description of Base Case (No Action) Alternative

Base case impacts to an inadvertent intruder are calculated considering two scenarios for potential inadvertent intrusion. One scenario is the assumed construction of a house directly into the disposed waste (intruder-construction scenario). The second scenario involves a potential situation in which an individual or individuals live in the house that is constructed and consumes food grown at the site (intruder-agriculture scenario). To calculate impacts from these intruder scenarios, waste spectrum 1 is assumed to be disposed of at the reference (base case) facility that is sited, designed, and operated as described in Chapter 3 and as set out in detail in Appendix E. The waste is disposed of in regular shallow land burial trenches with a standard thin cap. Waste spectrum 1 refers to the base case waste and much of the waste is assumed to be in an easily compressible, readily degradable waste form with relatively high leaching characteristics. The waste is assumed to be randomly disposed into the reference facility and no specific actions are taken to provide consideration of potential future inadvertent intrusion. For purposes of analysis, varying periods of institutional control from 50-2000 years are assumed to be in effect after closure during which inadvertent intrusion would not occur.

4.3.2 Costs and Impacts of Base Case (No Action) Alternative

The radiological hazard to a potential intruder for the base case (no action) alternative is listed in Table 4.2 for seven organs for several time periods following license termination. For this analysis, the termination of the disposal facility license was assumed to immediately follow a two-year closure period. The hazard listed (in mrem/yr to an individual) is summed over all 23 radionuclides considered in the analysis and volume-averaged over all 36 waste streams disposed into the disposal facility. As can be seen, the highest potential exposures are those to the bone. Over the first 500 years, potential exposures from the intruder-construction scenario drop by a factor of 6 from about 6 rems to about one rem. Over the next 1500 years, however, potential exposures are reasonably constant, and are still at about 800 mrem of 2000 years. A somewhat similar pattern is observed for potential exposures to the lung.

The potential exposures were conservatively calculated giving no credit (with the exception of activated metal) for the ability of waste form to reduce airborne dispersion of radionuclides or uptake by plant roots. That is, the waste is assumed to behave and disperse in a similar manner to ordinary dirt.

Other base case costs and impacts are summarized in Table 4.3 for waste spectrum 1. Also shown in Table 4.3 are the costs and impacts for disposal of waste spectra 2-4 at the base case reference disposal facility. The costs and impacts are calculated over 20 years of waste generation, processing, transport, and disposal. The format for Table 4.3 will be generally utilized throughout the remainder of the EIS to present the costs and impacts of the various alternatives analyzed. Included on the first page are population exposures from waste processing and transportation; occupational exposures for waste processing,

Table 4.2 Summary of Potential Inadvertent Intruder Hazard to Seven Organs for 36 Waste Streams (Waste Spectrum 1)

(mrem)

	Body	Bone	Liver	Thyroid	Kidney	Lung	G-I Tract
YR = 50.							
INT CONS	4.983E+03*	6.753E+03	6.290E+03	4.877E+03	5.482E+03	5.933E+03	4.878E+03
INT AGRI	6.461E+03	6.995E+03	6.867E+03	6.309E+03	6.546E+03	6.723E+03	6.319E+03
YR = 100.							
INT CONS	1.502E+03	3.095E+03	2.684E+03	1.407E+03	1.958E+03	2.341E+03	1.408E+03
INT AGRI	1.769E+03	2.482E+03	2.206E+03	1.703E+03	1.918E+03	2.068E+03	1.703E+03
YR = 150.							
INT CONS	5.454E+02	2.019E+03	1.638E+03	4.584E+02	9.670E+02	1.311E+03	4.587E+02
INT AGRI	5.891E+02	1.210E+03	1.013E+03	5.490E+02	7.475E+02	8.818E+02	5.465E+02
YR = 200.							
INT CONS	2.400E+02	1.623E+03	1.263E+03	1.588E+02	6.333E+02	9.556E+02	1.590E+02
INT AGRI	2.233E+02	7.881E+02	6.262E+02	1.923E+02	3.773E+02	5.032E+02	1.890E+02
YR = 300.							
INT CONS	1.058E+02	1.362E+03	1.026E+03	3.284E+01	4.542E+02	7.651E+02	3.300E+01
INT AGRI	6.818E+01	5.725E+02	4.328E+02	4.311E+01	2.068E+02	3.285E+02	3.941E+01
YR = 400.							
INT CONS	8.558E+01	1.255E+03	9.325E+02	1.859E+01	3.993E+02	7.191E+02	1.873E+01
INT AGRI	4.869E+01	5.168E+02	3.844E+02	2.623E+01	1.737E+02	2.990E+02	2.245E+01
YR = 500.							
INT CONS	7.808E+01	1.183E+03	8.687E+02	1.567E+01	3.637E+02	6.994E+02	1.579E+01
INT AGRI	4.336E+01	4.851E+02	3.568E+02	2.277E+01	1.572E+02	2.889E+02	1.894E+01
YR = 1000.							
INT CONS	5.869E+01	9.769E+02	6.822E+02	9.964E+00	2.570E+02	6.645E+02	1.004E+01
INT AGRI	3.112E+01	3.980E+02	2.782E+02	1.600E+01	1.101E+02	2.706E+02	1.208E+01
YR = 2000.							
INT CONS	4.491E+01	8.264E+02	5.482E+02	6.007E+00	1.817E+02	6.350E+02	6.048E+00
INT AGRI	2.251E+01	3.347E+02	2.219E+02	1.131E+01	7.691E+01	2.558E+02	7.317E+00

*The listed exposures are copied directly from the INTRUDE code output (See Appendix H).

Table 4.3 Costs and Other Impacts of Base Case (No Action) Alternative

	Waste Spectra			
Impacts	1	2	3	4
Short-term population exposures: (man-mrem)				
Processing by waste generator	0	0	7.86E+6	8.23E+6
Processing at regional processing center	0	0	3.74E+4	3.74E+4
Waste transportation	7.12E+5	7.03E+5	5.26E+5	2.16E+5
Short-term occupational exposures: (man-mrem)				
Processing by waste generator*	-	+1.68E+6	+1.18E+6	-3.50E+5
Processing at regional processing center	0	1.25E+5	2.45E+4	3.79E+4
Waste transportation	6.89E+6	6.49E+6	5.51E+6	2.19E+6
Waste disposal	3.05E+6	2.93E+6	2.49E+6	1.13E+6
Waste generation and transport costs: ($)				
Processing by waste generator*	-	+3.38E+8	+1.15E+9	+1.08E+9
Processing at regional processing center	0	3.63E+7	9.50E+7	1.05E+8
Waste transportation	2.49E+8	2.29E+8	1.88E+8	1.19E+8
Disposal costs: ($)				
Design and op.	1.85E+8	1.82E+8	1.81E+8	1.79E+8
Postoperational	3.82E+7	3.82E+7	3.82E+7	3.82E+7
Total	2.23E+8	2.20E+8	2.19E+8	2.17E+8
Unit ($\$/m^3$)	223	315	445	916
Energy use: (gal)*	--	+7.89E+6	+5.84E+7	+6.61E+7
Land use: (m^2)	3.47E+5	2.42E+5	1.71E+5	8.24E+4
Waste volume disposed: (m^3)				
Regular:				
o Chemical-Stable	2.95E+4	6.22E+4	1.16E+4	8.49E+3
o Chemical-Unstable	1.17E+5	7.40E+4	6.57E+4	6.57E+4
o No Chemical-Stable	2.23E+5	3.30E+5	4.04E+4	1.61E+5
o No Chemical-Unstable	6.30E+5	2.32E+5	1.15E+4	1.92E+3
o Total	1.00E+6	6.98E+5	4.93E+5	2.37E+5

Table 4.3 (continued)

Impacts	Waste Spectra 1	2	3	4
Total volume not acceptable: (m^3)	0	0	0	0
Direct intruder impacts:				
Body (mrem)				
o 100 C	1.502E+3	1.899E+3	3.113E+3	6.469E+3
A	1.769E+3	2.235E+3	3.667E+3	7.619E+3
o 500 C	7.808E+1	1.115E+2	1.582E+2	3.287E+2
A	4.336E+1	6.175E+1	8.781E+1	1.825E+2
Bone (mrem)				
o 100 C	3.095E+3	4.179E+3	6.340E+3	1.317E+4
A	2.482E+3	3.255E+3	5.111E+3	1.062E+4
o 500 C	1.183E+3	1.693E+2	2.396E+3	4.978E+3
A	4.851E+2	6.942E+2	9.823E+2	2.041E+3
Offsite releases from intrusion (at 100 years):				
Airborne impacts (man-millirem)				
o Body	2.242E+3	2.193E+3	2.016E+3	4.181E+3
o Bone	4.060E+4	3.970E+4	3.650E+4	7.569E+4
Waterborne impacts (millirem)				
o Body	8.475E-2	1.213E-1	1.716E-1	3.566E-1
o Bone	5.097E-1	7.297E-1	1.032E+0	2.145E+0

*Occupational exposures and processing costs by the waste generator for waste spectra 2-4 are presented as additional exposures and costs to those associated with waste spectrum 1. Similarly, energy use for waste spectra 2-4 are presented as an additional increment to that associated with waste spectrum 1.

transportation, and disposal; costs for waste processing and transportation; cost for disposal divided into design and operation costs, postoperational costs (closure and long-term care costs), and total disposal costs; total incremental energy used for processing, transportation, and disposal; land used for disposal; and total waste volume disposed of. Included on the second page are the long-term individual and population exposures resulting from disposal of the waste.

No short-term population exposures are shown for processing of the waste either at the point of generation or at a central processing facility. For the base case, it was assumed that none of the waste streams were subjected to incineration and in waste spectrum 1, no waste streams are delivered to a regional processing center. As discussed in Chapter 3, NRC also assumed for purposes of this EIS analysis, that operational releases from other waste processing operations (e.g., compaction and solidification) would be very small and as such they were not included. In any case, such potential releases would already be analyzed as part of licensing individual facilities. For this EIS, NRC is interested in estimating releases due to additional, more extensive, waste processing techniques. These releases are expected to be significant only for incineration. The population exposures due to transportation of the waste to the disposal facility were calculated to 7.12E+5 man-mrem.

Occupational exposures due to waste processing (also waste processing costs and energy use) are presented in this EIS as exposures in addition to those associated with waste spectrum 1. The NRC staff believes that it would be difficult to attempt to estimate the existing occupational exposures for waste management for all NRC and Agreement State licensees. In addition, the principal purpose of this EIS in regard to waste processing occupational exposures is to estimate incremental exposures associated with additional waste processing activities. This is believed to be in keeping with the purpose of this EIS.

Occupational exposures were also calculated for transportation and for handling of the waste during disposal operations (6.89E+6 man-mrem and 3.05E+6 man-mrem respectively).

Costs for waste processing are also presented as costs in addition to those associated with waste spectrum 1. Costs from transportation and disposal, however, were calculated. Unit disposal costs average \$223 per m^3 or \$6.32 per ft^3. The reader is referred to Appendices E, G, and Q for information about the costs and the methods by which they were determined. Other impact measures such as energy and land use were also calculated and are shown.

Page 2 of Table 4.2 shows the exposures to the inadvertent intruder calculated for the two scenarios, intruder-construction and intruder-agriculture. The exposures are calculated for two periods of active institutional control--100, and 500 years--and for two organs: whole body and bone. For purposes of analysis, each scenario is assumed to occur immediately following the end of the active institutional control period.

Finally, Table 4.2 shows the population exposures calculated due to releases of material to the offsite environment due to the intrusion event. The exposures are calculated at a time period of 100 years following license termination. Airborne impacts are calculated for the surrounding population within a 50-mile radius of the disposal facility. Waterborne impacts, however, are calculated to an individual. In the calculations, rainwater is assumed to erode the soil/waste mixture exposed by the intruder, and carry the contamination offsite to a nearby stream. The contaminated stream water is then assumed to be used by an individual for consumption, irrigation of crops, etc. As shown, the impacts to the inadvertent intruder himself are orders of magnitude higher than those to the surrounding population.

Tables 4.2 and 4.3 establish a baseline of cost and impact data calculated for the base case site and waste against which varying ways to mitigate these impacts can be compared. The data shows that the exposures calculated are relatively high at 100 years at which point they begin to decrease, leveling off at around 400-500 years. Although the exposures to the inadvertent intruder are not so high as to cause great (immediate life threatening) concern for the one or few individuals who might be exposed, some additional controls could be exercised that could reduce such potential exposures to lower levels during the 100-500 year time frame. Furthermore, the major portion of the exposures may be contributed by a few waste streams that could be controlled to reduce potential exposures.

4.3.2.1 Waste Spectra Nos. 2-4

Table 4.3 also presents the costs and impacts of disposing of improved waste forms, represented by waste spectra 2-4, at the reference base case facility. These have been included in this table principally to provide reference data on the other spectra for comparison with waste spectra 1 and to demonstrate two points:

1. As the volume of the waste is decreased through waste processing techniques such as compaction and incineration, exposure to an inadvertent intruder increases; and

2. Offsite population exposures from inadvertent intrusion activities are low and do not change significantly from one spectrum to another.

Considerable additional discussion regarding the effects of the waste spectra on the impact measures is provided in Chapter 5.

4.3.3 Description of Alternatives

NRC next analyzed a range of alternatives that could be applied to reduce the impacts to an inadvertent intruder and the costs and impacts of the alternatives. The alternatives analyzed fell into four categories:

1. Controlling the disposal of specific waste streams;

2. Waste form and packaging;

3. Institutional controls; and

4. Engineered and natural "intruder barriers" created through disposal facility design and operations.

Each is presented and analyzed below.

With respect to siting, site characteristics were not specifically analyzed with respect to reduction of intruder impacts. Considerations such as future population growth and land use development in the vicinity of the site and the extent of and economic significance of natural resources at the site could effect the potential for inadvertent intrusion. Such considerations would be applied in the siting of a near-surface disposal facility today. In general, selection of a site that does not have much resource value and which is not desirable for human activities would reduce the potential for inadvertent intrusion.

4.3.3.1 Controlling the Disposal of Specific Waste Streams

For this alternative, it is useful to examine the potential hazard of some individual waste streams and groups of waste streams in terms of intruder exposures. Care needs to be taken in interpreting the potential hazard of individual waste streams, however, since the actual potential intruder hazard at any particular site would come from a mixture of waste streams, not just one individual waste stream. This is particularly important for waste streams which are small in volume. In this section, no credit is again assumed for the ability of improved waste forms to reduce airborne and plant root uptake.

As an example, a summary of potential intruder hazard to whole body and bone for BWR ion-exchange resins is shown in Table 4.4. As can be seen, the potential exposures to whole body and bone are principally dominated by direct gamma radiation in the intruder-construction and intruder-agriculture scenarios. The differences in potential exposures between the four spectra for the two cases are a function of the waste processing option considered. That is, for waste spectrum 1, ion-exchange resins are assumed to be dewatered while for waste spectrum 2, half of the resins are solidified in cement and half in a synthetic polymer. The increase in volume relative to the dewatered condition coupled with the self-shielding provided by the cement leads to a reduction in exposures of about 2. For spectrum 3, all resins are solidified in a synthetic polymer. Due to the negligible self-shielding and the different volume increase factor, the potential hazard is somewhat higher than spectrum 2 but lower than spectrum 1. For spectrum 4, all resins are calcined and then solidified in a synthetic polymer. The greatly increased volume reduction brought about by the calcining operation leads to radionuclide concentrations in the final waste form about a factor of 18 higher than for spectrum 3. Even with the higher concentrations, however, potential exposures drop quickly to about 100 mrem/yr after 500 years.

Table 4.4 Potential Intruder Exposures to Whole Body and Bone for BWR Ion-Exchange Resins

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	6.197E+04	6.198E+04	3.005E+04	3.005E+04	3.098E+04	3.099E+04	5.577E+05	5.578E+05
INT AGRI	7.343E+04	7.356E+04	3.561E+04	3.569E+04	3.671E+04	3.678E+04	6.608E+05	6.620E+05
YR = 100.								
INT CONS	1.930E+04	1.931E+04	9.358E+03	9.365E+03	9.650E+03	9.656E+03	1.737E+05	1.738E+05
INT AGRI	2.287E+04	2.291E+04	1.109E+04	1.112E+04	1.143E+04	1.146E+04	2.058E+05	2.062E+05
YR = 150.								
INT CONS	6.087E+03	6.096E+03	2.915E+03	2.957E+03	3.043E+03	3.048E+03	5.478E+04	5.487E+04
INT AGRI	7.212E+03	7.229E+03	3.497E+03	3.507E+03	3.606E+03	3.614E+03	6.490E+04	6.506E+04
YR = 200.								
INT CONS	1.924E+03	1.932E+03	9.330E+02	9.380E+02	9.621E+02	9.662E+02	1.732E+04	1.739E+04
INT AGRI	2.280E+03	2.288E+03	1.105E+03	1.111E+03	1.140E+03	1.144E+03	2.052E+04	2.059E+04
YR = 300.								
INT CONS	1.993E+02	2.064E+02	9.671E+01	1.010E+02	9.967E+01	1.032E+02	1.794E+03	1.858E+03
INT AGRI	2.361E+02	2.404E+02	1.145E+02	1.171E+02	1.180E+02	1.202E+02	2.124E+03	2.162E+03
YR = 400.								
INT CONS	2.805E+01	3.431E+01	1.365E+01	1.745E+01	1.402E+01	1.716E+01	2.524E+02	3.088E+02
INT AGRI	3.317E+01	3.657E+01	1.613E+01	1.819E+01	1.658E+01	1.828E+01	2.981E+02	3.274E+02
YR = 500.								
INT CONS	1.097E+01	1.663E+01	5.363E+00	8.797E+00	5.484E+00	8.317E+00	9.872E+01	1.497E+02
INT AGRI	1.296E+01	1.593E+01	6.331E+00	8.134E+00	6.478E+00	7.966E+00	1.163E+02	1.417E+02
YR = 1000.								
INT CONS	8.769E+00	1.270E+01	4.281E+00	6.665E+00	4.385E+00	6.352E+00	7.892E+01	1.143E+02
INT AGRI	1.044E+01	1.255E+01	5.102E+00	6.379E+00	5.220E+00	6.273E+00	9.363E+01	1.113E+02
YR = 2000.								
INT CONS	8.361E+00	1.110E+01	4.072E+00	5.732E+00	4.181E+00	5.550E+00	7.525E+01	9.989E+01
INT AGRI	1.001E+01	1.157E+01	4.888E+00	5.833E+00	5.005E+00	5.785E+00	8.981E+01	1.027E+02

Also of interest is the potential thyroid hazard for BWR resins as shown in Table 4.5. BWR ion-exchange resins are estimated to contain a relatively high concentration of ^{129}I. Although several radionuclides contribute to the thyroid exposures, the high contribution from ^{129}I results in a somewhat different pattern of exposure than for whole body and bone. The calculations for both cases ignore the dilution of ^{129}I with stable iodine, which would act to reduce exposures.

A similar situation is shown in Table 4.6 for the BWR combustible trash stream. In waste spectrum 1, no special effort is made to reduce the volume of this waste stream while in waste spectrum 2, this stream is assumed to be compacted. In waste spectra 3 and 4, the stream is assumed to be incinerated and the ashes solidified in a synthetic polymer. Of interest are the effects of increased volume reduction. Even under extreme volume reduction--i.e., incineration--the potential hazard is under 500 mrem after 200 years and only a few millirems after 400 years.

This process may be potentially repeated for the other 34 waste streams. However, it is believed that presenting the results would be excessively voluminous. Table 4.6 was therefore prepared, which is a summary of potential intruder hazard to whole body and bone for 4 groups of waste streams under waste spectrum 2. (Waste spectrum 2 was selected since it represents readily achievable improvements in the form of waste shipped for disposal.) The 4 groups of waste streams are as follows:

- Group 1: LWR process waste streams (resins, filter media, solidified concentrated liquids and filter cartridges).
- Group 2: Trash waste streams for both fuel cycle and nonfuel cycle waste streams.
- Group 3: Other miscellaneous low-activity waste streams.
- Group 4: Miscellaneous "special" or high activity waste streams from both fuel-cycle and nonfuel-cycle waste streams.

As can be seen, exposures for group 1 (which is a volume-weighted average of 7 waste streams) are initially relatively high (e.g., about 5 rems at 100 years) but soon drop to relative low levels (e.g., about 500 mrem at 200 years and only a few mrem at 500 years). The hazard calculated for groups 2 and 3 are even less significant. However, the hazard from the group 4 waste streams (a mixture of 7 individual waste streams) appears to be significant. In addition, the potential hazard for group 4 waste streams does not decay as rapidly as the other group waste streams. For example, the hazard is approximately 10 times higher than group 1 at 100 years and a factor of 10^4 times higher than group 1 at 500 years.

The potential hazard in group 4 is principally contributed by only three waste streams, the total volume of which contributes only 20,200 m^3 out of the 698,000 m^3 disposed of in waste spectrum 2. These are:

Table 4.5 Potential Intruder Exposures to Thyroid for BWR Ion-Exchange Resins

	(mrem)			
	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
YR = 50.				
INT CONS	6.196E+04	3.004E+04	3.098E+04	5.576E+05
ING AGRI	7.345E+04	3.562E+04	3.672E+04	6.610E+05
YR = 100.				
INT CONS	1.930E+04	9.358E+03	9.650E+03	1.737E+05
INT AGRI	2.293E+04	1.113E+04	1.146E+04	2.063E+05
YR = 150.				
INT CONS	6.089E+03	2.953E+03	3.044E+03	5.480E+04
INT AGRI	7.281E+03	3.539E+03	3.641E+03	6.553E+04
YR = 200.				
INT CONS	1.927E+03	9.345E+02	9.633E+02	1.734E+04
INT AGRI	2.352E+03	1.150E+03	1.176E+03	2.117E+04
YR = 300.				
INT CONS	2.022E+02	9.843E+01	1.011E+02	1.820E+03
INT AGRI	3.102E+02	1.595E+02	1.551E+02	2.792E+03
YR = 400.				
INT CONS	3.097E+01	1.542E+01	1.548E+01	2.787E+02
INT AGRI	1.075E+02	6.117E+01	5.374E+01	9.669E+02
YR = 500.				
INT CONS	1.393E+01	7.158E+00	6.965E+00	1.254E+02
INT AGRI	8.730E+01	5.139E+01	4.365E+01	7.853E+02
YR = 1000.				
INT CONS	1.186E+01	6.154E+00	5.930E+00	1.067E+02
INT AGRI	8.483E+01	5.019E+01	4.242E+01	7.632E+02
YR = 2000.				
INT CONS	1.154E+01	5.999E+00	5.771E+00	1.039E+02
INT AGRI	8.444E+01	5.000E+01	4.222E+01	7.597E+02

Table 4.6 Summary of Potential Intruder Exposures to Whole Body and Bone for BWR Combustible Trash

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	2.190E+02	2.193E+02	4.380E+02	4.386E+02	8.760E+03	8.772E+03	8.760E+03	8.772E+03
INT AGRI	2.595E+02	2.601E+02	5.190E+02	5.201E+02	1.038E+04	1.040E+04	1.038E+04	1.040E+04
YR = 100.								
INT CONS	6.760E+01	6.785E+01	1.352E+02	1.357E+02	2.704E+03	2.714E+03	2.704E+03	2.714E+03
INT AGRI	8.008E+01	8.033E+01	1.602E+02	1.607E+02	3.203E+03	3.212E+03	3.203E+03	3.213E+03
YR = 150.								
INT CONS	2.135E+01	2.157E+01	4.269E+01	4.314E+01	8.538E+02	8.628E+02	8.538E+02	8.628E+02
INT AGRI	2.528E+01	2.542E+01	5.056E+01	5.084E+01	1.011E+03	1.017E+03	1.011E+03	1.017E+03
YR = 200.								
INT CONS	6.775E+00	6.978E+00	1.355E+01	1.396E+01	2.710E+02	2.791E+02	2.710E+02	2.791E+02
INT AGRI	8.017E+00	8.120E+00	1.603E+01	1.624E+01	3.207E+02	3.248E+02	3.207E+02	3.248E+02
YR = 300.								
INT CONS	7.335E-01	9.105E-01	1.471E+00	1.821E+00	2.942E+01	3.642E+01	2.942E+01	3.642E+01
INT AGRI	8.632E-01	9.402E-01	1.726E+00	1.880E+00	3.452E+01	3.758E+01	3.452E+01	3.758E+01
YR = 400.								
INT CONS	1.343E-01	2.891E-01	2.685E-01	5.782E-01	5.371E+00	1.156E+01	5.371E+00	1.156E+01
INT AGRI	1.519E-01	2.178E-01	3.039E-01	4.357E-01	6.072E+00	8.687E+00	6.072E+00	8.687E+00
YR = 500.								
INT CONS	7.306E-02	2.125E-01	1.461E-01	4.249E-01	2.922E+00	8.498E+00	2.922E+00	8.498E+00
INT AGRI	8.025E-02	1.389E-01	1.605E-01	2.778E-01	3.205E+00	5.529E+00	3.205E+00	5.529E+00
YR = 1000.								
INT CONS	6.077E-02	1.548E-01	1.215E-01	3.096E-01	2.431E+00	6.192E+00	2.431E+00	6.192E+00
INT AGRI	6.830E-02	1.078E-01	1.366E-01	2.156E-01	2.727E+00	4.287E+00	2.727E+00	4.287E+00
YR = 2000.								
INT CONS	5.564E-02	1.183E-01	1.113E-01	2.366E-01	2.225E+00	4.731E+00	2.225E+00	4.731E+00
INT AGRI	6.401E-02	9.071E-02	1.280E-01	1.814E-01	2.556E+01	3.606E+00	2.556E+00	3.606E+00

Table 4.7 Summary of Potential Intruder Exposures to Whole Body and Bone for Four Groups of Waste Streams Under Waste Spectrum 2

(mrem)

	Group 1		Group 2		Group 3		Group 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	1.409E+04	1.412E+04	4.449E+02	4.467E+02	2.572E+01	2.651E+01	6.102E+04	1.312E+05
INT AGRI	1.670E+04	1.675E+04	5.375E+02	5.483E+02	4.938E+01	9.470E+01	9.417E+04	1.146E+05
YR = 100.								
INT CONS	4.347E+03	4.371E+03	1.364E+02	1.377E+02	7.989E+00	8.236E+00	1.746E+04	8.066E+04
INT AGRI	5.150E+03	5.174E+03	1.633E+02	1.688E+02	1.426E+02	2.856E+01	2.022E+04	4.826E+04
YR = 150.								
INT CONS	1.373E+03	1.395E+03	4.312E+01	4.431E+01	2.545E+00	2.635E+00	8.338E+03	6.680E+04
INT AGRI	1.626E+03	1.640E+03	5.162E+01	5.426E+01	4.440E+00	8.976E+00	7.598E+03	3.216E+04
YR = 200.								
INT CONS	4.362E+02	4.562E+02	1.375E+01	1.483E+01	8.330E-01	8.765E-01	5.305E+03	6.020E+04
INT AGRI	5.160E+02	5.264E+02	1.653E+01	1.821E+01	1.476E+00	3.126E+00	3.858E+03	2.622E+04
YR = 300.								
INT CONS	4.790E+01	6.511E+01	1.566E+00	2.507E+00	1.250E-01	1.513E-01	3.744E+03	5.359E+04
INT AGRI	5.595E+01	6.372E+01	2.004E+00	3.219E+00	2.890E+01	8.474E-01	2.165E+03	2.216E+04
YR = 400.								
INT CONS	9.193E+00	2.445E+01	3.476E-01	1.185E+00	5.494E-02	7.970E-02	3.317E+03	4.973E+04
INT AGRI	1.018E+01	1.677E+01	5.549E-01	1.660E+00	1.753E-01	6.365E-01	1.835E+03	2.040E+04
YR = 500.								
INT CONS	5.214E+00	1.897E+01	2.190E-01	9.747E-01	4.799E-02	7.261E-02	3.057E+03	4.691E+04
INT AGRI	5.549E+00	1.137E+01	4.037E-01	1.450E+00	1.633E-01	6.115E-01	1.668E+03	1.919E+04
YR = 1000.								
INT CONS	4.287E+00	1.361E+01	1.773E-01	6.881E-01	4.720E-02	7.168E-02	2.294E+03	3.876E+04
INT AGRI	4.705E+00	8.605E+00	3.576E-01	1.250E+00	1.559E-01	5.781E-01	1.189E+03	1.575E+04
YR = 2000.								
INT CONS	3.859E+00	1.010E+01	1.546E-01	4.945E-01	4.714E-02	7.139E-02	1.749E+03	3.280E+04
INT AGRI	4.373E+00	7.020E+00	3.212E-01	1.067E+00	1.444E-01	5.205E-01	8.495E+02	1.324E+04

- o LWR decontamination resins (1.933E+4 m^3)
- o Sources (51.51 m^3)
- o LWR nonfuel reactor core components (797.5 m^3)

The potential hazard as a function of time for whole body and bone for LWR decontamination resins and sources is given in Tables 4.8 and 4.9, respectively. The potential hazard for seven organs for LWR nonfuel core components is shown in Table 4.10.

There is considerable uncertainty about the actual radionuclide concentrations in these waste streams. For example, the LWR decontamination resin stream is somewhat hypothetical and is based upon an assumption that all LWRs will undergo, in the future, a periodic full-scale decontamination process every 7 years. The purpose of such full-scale primary decontamination operations is to reduce plant personnel exposure by removing crud accumulated on surfaces in contact with the primary coolant. Although full-scale primary coolant decontamination operations have not been routinely performed in the past, NRC has fairly recently (October 1980) published an environmental impact statement regarding such an operation being performed at the Dresden Unit 1 nuclear power station (Ref. 6). Dresden 1 is a 200 MW(e) dual-cycle BWR which, over its 20-year operating life, has built up a thin layer of radioactive oxide deposits (principally Co-60) over the inner surfaces of pipes, valves, pumps, etc. In the decontamination process, a decontamination solution is circulated and flushed through the coolant system, which dissolves the crud deposits. The decontamination solution is then removed from the coolant system and processed through an evaporator. The evaporator bottoms are then solidified in vinyl ester styrene (a synthetic polymer), which are then shipped offsite for disposal. Since the solidified waste will contain a large quantity of chelating agents, the waste will be disposed only at a disposal facility located in an arid environment and segregated from other waste by at least 3 meters of soil (Ref. 6).

Although the Dresden 1 decontamination operation can be considered in some respects a prototype of future full-scale primary coolant decontamination operations at other power plants, it is still difficult to project future volumes and other characteristics of decontamination wastes. There may be a number of possible decontamination processes utilized--e.g., from dilute chemical processes on an annual basis to more concentrated processes at intervals of several years--and the waste streams generated may vary in kind (e.g., resins, solidified liquids) and in volume from operation to operation and plant to plant. Other plant-specific factors which would influence the volumes, radioactivity content, and other characteristics of the wastes generated would include the operating history of the plant (e.g., history of fuel failures), the design of the plant and liquid clean-up and processing systems, the chemistry of the primary coolant, and the length of time between decontamination operations. Institutional matters such as the policies of specific utilities could also be a consideration.

Notwithstanding this uncertainty, the NRC staff believes that wastes generated from routine full-scale decontamination of reactor primary coolant systems should be represented in the low-level waste source data base. For this EIS,

Table 4.8 Summary of Potential Intruder Hazard to Whole Body and Bone for Postulated Future LWR Decontamination Resin Stream

	(mrem)	
	Body	Bone
YR = 50.		
INT CONS	2.805E+04	1.187E+05
ING AGRI	2.927E+04	6.654E+04
YR = 100.		
INT CONS	7.522E+03	8.926E+04
INT AGRI	5.193E+03	3.829E+04
YR = 150.		
INT CONS	6.032E+03	8.170E+04
INT AGRI	3.664E+03	3.411E+04
YR = 200.		
INT CONS	5.356E+03	7.642E+04
INT AGRI	3.072E+03	3.158E+04
YR = 300.		
INT CONS	4.682E+03	6.923E+04
INT AGRI	2.598E+03	2.843E+04
YR = 400.		
INT CONS	4.265E+03	6.438E+04
INT AGRI	2.340E+03	2.637E+04
YR = 500.		
INT CONS	3.943E+03	6.076E+04
INT AGRI	2.142E+03	2.484E+04
YR = 1000.		
INT CONS	2.962E+03	5.026E+04
INT AGRI	1.527E+03	2.041E+04
YR = 2000.		
INT CONS	2.260E+03	4.257E+04
INT AGRI	1.090E+03	1.718E+04

Table 4.9 Summary of Potential Inadvertent Intruder Hazard for Whole Body and Bone for Postulated Sources Stream

	(mrem)	
	Body	Bone
YR = 50.		
INT CONS	1.064E+07	1.074E+07
INT AGRI	1.267E+07	1.276E+07
YR = 100.		
INT CONS	3.358E+06	3.450E+06
INT AGRI	3.983E+06	4.045E+06
YR = 150.		
INT CONS	1.064E+06	1.149E+06
ING AGRI	1.258E+06	1.300E+06
YR = 200.		
INT CONS	3.409E+05	4.195E+05
INT AGRI	3.998E+05	4.337E+05
YR = 300.		
INT CONS	4.036E+04	1.079E+05
INT AGRI	4.382E+04	7.107E+04
YR = 400.		
INT CONS	9.614E+03	6.771E+04
INT AGRI	7.920E+03	3.118E+04
YR = 500.		
INT CONS	5.777E+03	5.573E+04
INT AGRI	3.857E+03	2.384E+04
YR = 1000.		
INT CONS	2.562E+03	2.604E+04
INT AGRI	1.631E+03	1.102E+04
YR = 2000.		
INT CONS	5.661E+02	5.752E+03
INT AGRI	3.604E+02	2.434E+03

Table 4.10 Summary of Potential Inadvertent Intruder Exposures to Seven Organs for LWR Nonfuel Reactor Core Components

(mrem)

	Body	Bone	Liver	Thyroid	Kidney	Lung	GI Tract
YR = 50.							
INT CONS	7.363E+04	7.406E+04	7.365E+04	7.361E+04	7.361E+04	7.367E+04	7.362E+04
INT AGRI	8.733E+04	9.161E+04	8.749E+04	8.718E+04	8.718E+04	8.720E+04	8.725E+04
YR = 100.							
INT CONS	3.587E+02	6.559E+02	3.698E+02	3.485E+02	3.485E+02	3.572E+02	3.524E+02
INT AGRI	5.182E+02	3.460E+03	6.270E+02	4.162E+02	4.162E+02	4.196E+02	4.599E+02
YR = 150.							
INT CONS	2.555E+02	4.595E+02	2.631E+02	2.485E+02	2.485E+02	2.544E+02	2.511E+02
INT AGRI	3.678E+02	2.392E+03	4.427E+02	2.976E+02	2.976E+02	3.000E+02	3.278E+02
YR = 200.							
INT CONS	2.527E+02	3.925E+02	2.580E+02	2.479E+02	2.479E+02	2.520E+02	2.497E+02
INT AGRI	3.453E+02	1.739E+03	3.969E+02	2.970E+02	2.970E+02	2.986E+02	3.177E+02
YR = 300.							
INT CONS	2.494E+02	3.156E+02	2.159E+02	2.471E+02	2.471E+02	2.491E+02	2.480E+02
INT AGRI	3.191E+02	9.841E+02	3.436E+02	2.960E+02	2.960E+02	2.968E+02	3.059E+02
YR = 400.							
INT CONS	2.474E+02	2.788E+02	2.487E+02	2.463E+02	2.463E+02	2.473E+02	2.468E+02
INT AGRI	3.062E+02	6.278E+02	3.181E+02	2.950E+02	2.950E+02	2.954E+02	2.998E+02
YR = 500.							
INT CONS	2.461E+02	2.610E+02	2.467E+02	2.455E+02	2.455E+02	2.460E+02	2.458E+02
INT AGRI	2.996E+02	4.594E+02	3.055E+02	2.940E+02	2.940E+02	2.942E+02	2.964E+02
YR = 1000.							
INT CONS	2.417E+02	2.424E+02	2.418E+02	2.416E+02	2.416E+02	2.417E+02	2.417E+02
INT AGRI	2.899E+02	3.083E+02	2.906E+02	2.892E+02	2.892E+02	2.893E+02	2.895E+02
YR = 2000.							
INT CONS	2.341E+02	2.344E+02	2.341E+02	2.340E+02	2.340E+02	2.341E+02	2.340E+02
INT AGRI	2.804E+02	2.941E+02	2.810E+02	2.799E+02	2.799E+02	2.799E+02	2.801E+02

it is assumed that every operating LWR undergoes a full-scale primary coolant decontamination operation every 7 years using a dilute chemical decontamination process. Generated wastes are represented by spent ion exchange resins containing significant quantities of chelating agents and other decontamination chemicals.

To estimate concentrations, data was used based upon crud scrapings from the internals of a light water reactor. Use of this procedure to estimate radionuclide concentrations in this stream results in estimated transuranic concentrations in considerable excess of 10 nCi/gm. Thus, the waste stream as postulated would not be acceptable for disposal at existing LLW disposal facilities. Use of crud scrapings to estimate concentrations is believed to be conservative and perhaps overconservative, since data from the Dresden 1 decontamination operations indicates that the generated decontamination waste will have transuranic concentrations less than 10 nCi/gm (Ref. 6). Despite this, however, the NRC staff believes that the low Dresden 1 transuranic concentrations may not be indicative of all future large-scale decontamination operations. As discussed above, the characteristics of future decontamination wastes are uncertain and may be a function of a number of plant-specific conditions. Thus, it would appear to be appropriate to determine radionuclide concentrations in future full-scale decontamination waste streams on a plant-specific basis.

Another waste stream for which there is little information at this time is the sources waste stream. This waste stream is a composite of sealed sources, foils, and similar wastes, and in determining the radionuclide concentrations, the higher activity examples were given greatest consideration. As shown in Table 4.9, the calculated hazard is extremely high, which is unrealistic and is a function of the extremely small volume (51.5 m^3) of this waste stream. In reality, the actual potential impacts would be much lower due to the considerable dilution that would occur with the other lower activity waste streams. Given this, however, the table is still useful in that it illustrates the relative contribution of total hazard from different isotopes. Initially, most of the hazard is provided by gamma radiation emitted by Cs-137 (see Appendix D). As the cesium decays away (noted by the characteristic decay by a factor of 10 every 100 years), most of the longer-term hazard is provided by the assumed high concentrations of americium from large americium sources. Currently, disposal of large americium sources is not permitted in existing disposal facilities. NRC has, however, included such sources in the waste spectra to allow an estimate of the possible hazard of their disposal into a near-surface disposal facility.

The third stream--LWR nonfuel reactor core components--is composed of activated metal and the potential hazard is shown on Table 4.10. Since the waste stream is composed of activated metal, most of the hazard is from direct gamma radiation. As can be seen, the estimated hazard is somewhat higher than the group 1 process waste streams but considerably less than the other two streams discussed above.

Given the above analysis, it appears that by controlling the disposal of a few waste streams, potential intruder hazards could be considerably reduced. For example, Table 4.11 shows the potential hazard to whole body and bone from all waste streams assuming that the LWR decontamination stream (high TRU content) and the sources streams (large americium sources) are excluded from near-surface disposal. Comparing Table 4.11 with Tables 4.2 and 4.3, it can be seen that removal of these two streams results in only a slightly smaller hazard over the first few hundred years, which is the time period over which most of the hazard is dominated by direct gamma radiation from the disposed waste. However, the reduction in the potential long-term hazard is significant--i.e., only a few millirem rather than potentially several hundred millirem. Similarly, Table 4.7 is repeated as Table 4.12, except that the 2 waste streams in question are again removed from group 4. As can be seen, removal of these waste streams results in an overall reduction of hazard. The long-term hazard associated with group 4 is reduced by several orders of magnitude.

4.3.4 Waste Form and Packaging

Another way in which potential intruder exposures can be reduced is through improvements in waste form and packaging. These improvements can lead to reduced exposures in two principal ways:

1. The potential for the waste to be dispersed into a form which can be readily inhaled or taken up by plant roots is reduced if the waste is placed into a stable form or package; and

2. The likelihood that the intruder will stay in contact with the waste (e.g., construct in it, grow crops in it) is reduced if the waste is placed into a stable form or package.

4.3.4.1 Effectiveness of Waste Form

If the waste is contacted through inadvertent intrusion, then potential inhalation exposures should be reduced if the waste is in a stable, less dispersible waste form. Similarly, exposure pathways which occur through consumption of food grown in contaminated ground should also be reduced if the waste were in a low leaching form. In order for radionuclides to be taken up by plants, the radionuclides must first be dissolved and leached out of the waste.

Different conclusions regarding the effect of waste form have been reached by other investigators performing analyses regarding work on waste classification. For example, one group of investigators, in a study which followed their work on waste classification, questioned the option of placing the waste into a durable form, and concluded that it may be better to disperse the waste into soil rather than concentrate it into a waste package where it may be encountered by an intruder (Ref. 7). As stated by the authors:

> Packaging waste in durable containers has generally been considered beneficial to waste disposal. This is not always correct, because an effective container prevents the waste from being diluted with the

Table 4.11 Summary of Potential Intruder Exposures to Whole Body and Bone From 34 Waste Streams

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	3.969E+03	3.981E+03	4.889E+03	4.906E+03	8.127E+03	8.151E+03	1.693E+04	1.698E+04
INT AGRI	5.344E+03	5.149E+03	6.720E+03	6.438E+03	1.090E+04	1.052E+04	2.271E+04	2.191E+04
YR = 100.								
INT CONS	1.207E+03	1.214E+03	1.484E+03	1.494E+03	2.473E+03	2.487E+03	5.152E+03	5.181E+03
INT AGRI	1.492E+03	1.563E+03	1.848E+03	1.950E+03	3.054E+03	3.195E+03	6.362E+03	6.655E+03
YR = 150.								
INT CONS	3.812E+02	3.865E+02	4.686E+02	4.764E+02	7.811E+02	7.917E+02	1.627E+03	1.649E+03
INT AGRI	4.623E+02	4.930E+02	5.707E+02	6.151E+02	9.466E+02	1.008E+03	1.972E+03	2.099E+03
YR = 200.								
INT CONS	1.211E+02	1.257E+02	1.490E+02	1.556E+02	2.482E+02	2.573E+02	5.170E+02	5.360E+02
INT AGRI	1.461E+02	1.578E+02	1.803E+02	1.971E+02	2.991E+02	3.221E+02	6.232E+02	6.708E+02
YR = 300.								
INT CONS	1.336E+01	1.716E+01	1.648E+01	2.196E+01	2.733E+01	3.488E+01	5.693E+01	7.267E+01
INT AGRI	1.597E+01	1.919E+01	1.973E+01	2.439E+01	3.258E+01	3.873E+01	6.786E+01	8.056E+01
YR = 400.								
INT CONS	2.624E+00	5.960E+00	3.280E+00	8.096E+00	5.327E+00	1.197E+01	1.110E+01	2.493E+01
INT AGRI	3.061E+00	5.122E+00	3.817E+00	6.793E+00	6.147E+00	9.975E+00	1.279E+01	2.071E+01
YR = 500.								
INT CONS	1.526E+00	4.522E+00	1.925E+00	6.251E+00	3.078E+00	9.041E+00	6.412E+00	1.883E+01
INT AGRI	1.756E+00	3.462E+00	2.205E+00	4.668E+00	3.475E+00	6.598E+00	7.224E+00	1.367E+01
YR = 1000.								
INT CONS	1.290E+00	3.312E+00	1.617E+00	4.536E+00	2.596E+00	6.619E+00	5.407E+00	1.379E+01
INT AGRI	1.521E+00	2.670E+00	1.906E+00	3.566E+00	2.997E+00	5.029E+00	6.230E+00	1.041E+01
YR = 2000.								
INT CONS	1.183E+00	2.537E+00	1.474E+00	3.429E+00	2.379E+00	5.073E+00	4.956E+00	1.057E+01
INT AGRI	1.424E+00	2.265E+00	1.779E+00	2.993E+00	2.807E+00	4.254E+00	5.834E+00	8.799E+00

Table 4.12 Summary of Potential Intruder Exposures to Whole Body and Bone for Four Waste Groups of 34 Waste Streams Under Waste Spectrum 2

(mrem)

	Group 1		Group 2		Group 3		Group 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	1.409E+04	1.412E+04	4.449E+02	4.467E+02	2.572E+01	2.651E+01	7.716E+04	7.808E+04
INT AGRI	1.670E+04	1.675E+04	5.375E+02	5.483E+02	4.938E+01	9.470E+01	2.001E+05	1.631E+05
YR = 100.								
INT CONS	4.347E+03	4.371E+03	1.364E+02	1.377E+02	7.989E+00	8.236E+00	2.096E+04	2.125E+04
INT AGRI	5.150E+03	5.174E+03	1.633E+02	1.688E+02	1.426E+01	2.856E+01	3.532E+04	4.592E+04
YR = 150.								
INT CONS	1.373E+03	1.395E+03	4.312E+01	4.431E+01	2.545E+00	2.635E+00	6.619E+03	6.724E+03
INT AGRI	1.626E+03	1.640E+03	5.162E+01	5.426E+01	4.440E+00	8.976E+00	9.630E+03	1.414E+04
YR = 200.								
INT CONS	4.362E+02	4.562E+02	1.375E+01	1.483E+01	8.330E-01	8.765E-01	2.109E+03	2.154E+03
INT AGRI	5.160E+02	5.264E+02	1.653E+01	1.821E+01	1.476E+00	3.126E+00	2.947E+03	4.450E+03
YR = 300.								
INT CONS	4.790E+01	6.511E+01	1.566E+00	2.507E+00	1.250E-01	1.513E-01	2.422E+02	2.564E+02
INT AGRI	5.595E01	6.372E+01	2.004E+00	3.219E+00	2.890E-01	8.474E-01	3.258E+02	5.323E+02
YR = 400.								
INT CONS	9.193E+00	2.445E+01	3.476E-01	1.185E+00	5.494E-02	7.970E-02	5.681E+01	6.404E+01
INT AGRI	1.018E+01	1.677E+01	5.549E-01	1.660E+00	1.753E-01	6.365E-01	7.200E+01	1.276E+02
YR = 500.								
INT CONS	5.214E+00	1.897E+01	2.190E-01	9.747E-01	4.799E-02	7.261E-02	3.823E+01	4.271E+01
INT AGRI	5.549E+00	1.137E+01	4.037E-01	1.450E+00	1.633E-01	6.115E-01	4.654E+01	6.069E+01
YR = 1000.								
INT CONS	4.287E+00	1.361E+01	1.773E-01	6.881E-01	4.720E-02	7.168E-02	3.547E+01	3.700E+01
INT AGRI	4.705E+00	8.605E+00	3.576E-01	1.250E+00	1.559E-01	5.781E-01	4.245E+01	4.562E+01
YR = 2000.								
INT CONS	3.859E+00	1.010E+01	1.546E-01	4.945E-01	4.714E-02	7.139E-02	3.428E+01	3.513E+01
INT AGRI	4.373E+00	7.020E+00	3.212E-01	1.067E+00	1.444E-01	5.205E-01	4.102E+01	4.327E+01

> surrounding soil. If the reclaimer scenarios are limiting, as for Class D and Class E waste [waste determined by the authors to be suitable for disposal by shallow land burial and by a sanitary landfill, respectively (see Ref. 3)] and the container keeps the waste from being diluted, the potential dose rate to the reclaimer can be higher.
>
> If the ground water or well water pathways are most restrictive, then the container or chemical form of the waste can greatly reduce the rate at which the isotopes enter the aquifer.

Other author questioned the practice of using plastic bags to cover pieces of transuranic-contaminated equipment to control the spread of contamination during waste handling and disposal. The author observed an example where waste which had been disposed of 14 years previously at the Savannah River Plant (a humid environment) was exhumed and examined. The waste material which had been disposed in plastic bags was still intact. In some cases the writing on paper within the plastic bags was still legible. The authors were concerned that at some indefinite time in the future, an individual could potentially dig into the disposed waste to retrieve an artifact either for its archeologic value or to make some use out of it. The authors concluded that it may be desirable to place potentially useful items in a degradable wrapping which would be adequate for handling and disposal but would quickly degrade in soil. The wrapped waste material would then tend to degrade, which would reduce its value as a potential artifact. As the authors state (Ref. 5):

> This indicated that the goal of providing improved packages to slow the migration of transuranics from the burial ground may be undesirable. The analyses that we have done indicate that the problem of movement from the area by leaching or erosion is much lower than the problem of artifacts remaining. This has led to the conclusion that degradable packages are of lower potential hazard than packages designed for long-time containment.

These conclusions, however, can be viewed differently. Assuming that a waste form and package is allowed to quickly degrade so that the waste radionuclides are "diluted," then the only way that dilution of the waste could occur is by high ground-water infiltration which would leach the radionuclides out of the waste, dispersing them in the soil. Such an action trades a hypothetical exposure to a few individuals intruding into the disposal facility for a fairly certain increased level of potential exposure to populations through increased potential for ground-water migration. The potential for exposures from one pathway would be increased while theoretically another pathway would be reduced. (As discussed in Chapter 5, this would also lead to increased long-term costs by the site owner for care and maintenance of the closed disposal facility.) Even under very extreme ground-water infiltration and leaching conditions, however, carried out for hundreds of years, almost all of the radionuclides would still be in the immediate disposal facility location. (This would be particularly true for the heavy metals.) Given the decomposition of the waste form and packages that would be allowed to occur, the radionuclides would actually be in a form which could be more readily dispersed into respirable particles or taken up by plant roots. Rather than decreasing potential intruder exposures, degradable waste packages and forms could increase such exposures, both in the likelihood that intrusion scenarios such as housing construction would occur (see Section 4.3.4.3) and in the impacts that could result if the intrusion scenarios do occur. Furthermore, the potential for ground-water migration would be increased.

In the unlikely event that the facility is intruded into by an artifact hunter or for archeological purposes, improved waste forms and packages would also reduce potential impacts. The less degradation of waste forms that occur, the less exposures would be received by the artifact hunter while searching for the artifact. Assuming for the moment that a potentially valuable artifact was located and some time was subsequently spent polishing the artifact, then the less the artifact was degraded or corroded, the less the likelihood of respirable particles flying off. In addition, less time would be spent polishing the artifact. Even though ancient waste dumps are often inspected by current archeologists to acquire information about past civilizations, such investigation is done because the recordkeeping abilities of past civilizations was frequently poor and there is frequently little other way to acquire such information. The ability for civilization to maintain information has drastically improved and it is unlikely that future archeologists would need to exhume disposed waste to study our civilization. Archeology is a painstaking science and articles are not just dug up. Considerable research is generally performed to relate objects discovered with other records or information regarding the era. Assuming that a potentially valuable artifact is discovered, then some investigation would be required by the artifact hunter to confirm the value. This increases the chances that the potential hazard would be discovered.

The potential for waste form to reduce intruder impacts can also be illustrated numerically. To do so, NRC analyzed two cases: a "waste form credit case" and a "waste form no-credit case."

In the "waste form credit case," the degree to which radionuclides are dispersed from waste or are taken up by plant roots is assumed to be a function of waste form. For example, resins solidified in a synthetic polymer would be expected to be less leachable and less dispersible than dewatered resins. The relative degree to which wastes can be dispersed from waste is given by the following equation:

$$f_W = 10^{(I5-3)} \times 10^{(1-I9)}, \text{ where}$$

f_W is the waste form and package factor for dispersion;

I5 is the dispersibility index; and

I9 is the accessibility index.

The relative degree to which wastes may be taken up by plant roots is given by the following equation:

$f_w = M_o \times 10^{(1-I9)} \times Mult\ (I6,I7,I9)$ where,

f_w is the waste form and package factor for exposures through the food pathway;

M_o is the leach fraction of unsolidified wastes; and

Mult (I6,I7,I9) is the reduction due to solidification and the presence or absence of chelating chemicals which is characterized by the leachibility index (I6), chemical content index (I7), and whether waste streams containing chelating or chemical agents have been segregated from other wastes during disposal (the segregation index, IS).

The description of the derivation and use of these equations is given in Appendix G, and they indicate a reduction in dispersion and plant uptake depending upon waste form. It is believed that the above types of relationships assumed are reasonable; however, it is difficult to give precise values to the parameters or to say with certainty that the relationships will hold over long time periods. Nonetheless, they can be used to estimate a level of hazard from potential inadvertent intrusion given credit for a stable, nondispersible, low leaching waste form.

In the waste form no-credit case, which was the case assumed for all the previous analyses in this chapter, no credit is assumed to be taken for waste form in reducing plant uptake and airborne dispersion. Except for activated metals, the waste is assumed to disperse in a similar manner as soil. No credit is given for improvements in waste leaching characteristics to reduce plant uptake or airborne dispersion.

4.3.4.2 Analysis of Impacts

Tables 4.13 and 4.14 present a summary of potential inadvertent intruder exposures to whole body and bone as a function of time and waste spectrum, assuming that all 36 waste streams are uniformly mixed together and randomly disposed within the reference disposal facility trenches. Table 4.13 presents the "credit case" and Table 4.14 presents the "no-credit case." The time periods indicate the active institutional control period following the termination of the disposal facility license, which for this analysis is assumed to immediately follow a 2-year closure period.

The potential hazards (in mrem/yr) shown are summed over all 23 radionuclides considered in the analysis and volume averaged over all 36 waste streams, and are again shown for the two intruder scenarios--i.e., the "intruder-construction" scenario and the "intruder-agriculture" scenario. These potential hazard levels are calculated based upon a mixture of all waste streams having a range of activities. No cost or other impact data was calculated for this part of the analysis due to the narrow range of the question being addressed and the number of alternatives considered.

As shown in Table 4.13 for the credit case, the potential exposures for all four spectra drop off as a function of time due to decay of the radioisotopes

Table 4.13 Summary of Potential Intruder Exposure to Whole Body and Bone From 36 Waste Streams (Credit Case)

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.*								
INT CONS**	4.875E+03	4.880E+03	6.160E+03	6.163E+03	1.010E+04	1.010E+04	2.099E+04	2.099E+04
INT AGRI	6.335E+03	5.914E+03	8.070E+03	7.375E+03	1.305E+04	1.205E+04	2.711E+04	2.504E+04
YR = 100.								
INT CONS	1.408E+03	1.412E+03	1.763E+03	1.765E+03	2.921E+03	2.924E+03	6.070E+03	6.077E+03
INT AGRI	1.708E+03	1.711E+03	2.139E+03	2.114E+03	3.529E+03	3.489E+03	7.333E+03	7.251E+03
YR = 150.								
INT CONS	4.585E+02	4.621E+02	5.766E+02	5.788E+02	9,505E+02	9.535E+02	6.070E+03	6.077E+03
INT AGRI	5.476E+02	5.581E+02	6.872E+02	6.931E+02	1.131E+03	1.137E+03	2.350E+03	2.363E+03
YR = 200.								
INT CONS	1.588E+02	1.621E+02	2.019E+02	2.039E+02	3.283E+02	3.311E+02	6.823E+02	6.881E+02
INT AGRI	1.889E+02	1.944E+02	2.398E+02	2.441E+02	3.895E+02	3.945E+02	8.095E+02	8.198E+02
YR = 300.								
INT CONS	3.282E+01	3.575E+01	4.411E+01	4.597E+01	6.699E+01	6.954E+01	1.392E+02	1.445E+02
INT AGRI	3.892E+01	4.136E+01	5.234E+01	5.455E+01	7.933E+01	8.181E+01	1.649E+02	1.700E+02
YR = 400.								
INT CONS	1.855E+01	2.120E+01	2.593E+01	2.766E+01	3.749E+01	3.986E+01	7.790E+01	8.284E+01
INT AGRI	2.196E+01	2.375E+01	3.077E+01	3.239E+01	4.435E+01	4.605E+01	9.216E+01	9.570E+01
YR = 500.								
INT CONS	1.562E+01	1.805E+01	2.196E+01	2.360E+01	3.150E+01	3.374E+01	6.545E+01	7.011E+01
INT AGRI	1.848E+01	1.999E+01	2.606E+01	2.742E+01	3.725E+01	3.860E+01	7.740E+01	8.021E+01
YR = 1000.								
INT CONS	9.865E+00	1.169E+01	1.381E+01	1.516E+01	1.990E+01	2.176E+01	4.135E+01	4.523E+01
INT AGRI	1.169E+01	1.278E+01	1.640E+01	1.741E+01	2.352E+01	2.444E+01	4.887E+01	5.078E+01
YR = 2000.								
INT CONS	5.77E+00	7.275E+00	8.139E+00	9.285E+00	1.186E+01	1.345E+01	2.465E+01	2.795E+01
INT AGRI	6.982E+00	7.840E+00	9.691E+00	1.054E+01	1.401E+01	1.477E+01	2.911E+01	3.068E+01

*"YR = " means number of years following termination of the disposal facility license.

**"INT-CONS" means intruder-construction scenario.
"INT-AGRI" means intruder-agriculture scenario.

Table 4.14 Summary of Potential Intruder Exposures to Whole Body and Bone From 36 Waste Streams (No-Credit Case)

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.*								
INT CONS**	4.983E+03	6.753E+03	6.316E+03	8.849E+03	1.032E+04	1.390+04	2.144E+04	2.889E+04
INT AGRI	6.461E+03	6.995E+03	8.280E+03	9.044E+03	1.335E+04	1.443E+04	2.774E+04	3.000E+04
YR = 100								
INT CONS	1.502E+03	3.095E+03	1.899E+03	4.179E+03	3.113E+03	6.340E+03	6.469E+03	1.317E+04
INT AGRI	1.769E+03	4.482E+03	2.235E+03	3.255E+03	3.667E+03	5.111E+03	7.619E+03	1.062E+04
YR = 150.								
INT CONS	5.454E+02	2.019E+03	7.012E+02	2.811E+03	1.127E+03	4.111E+03	2.342E+03	8.544E+03
INT AGRI	5.891E+02	1.210E+03	7.492E+02	1.639E+03	1.219E+03	2.478E+03	2.534E+03	5.149E+03
YR = 200.								
INT CONS	2.400E+02	1.623E+02	3.183E+02	2.299E+03	4.931E+02	3.295E+03	1.025E+03	6.847E+03
INT AGRI	2.233E+02	7.881E+02	2.898E+02	1.098E+02	4.606E+02	1.604E+03	9.571E+02	3.334E+03
YR = 300.								
INT CONS	1.058E+02	1.362E+03	1.487E+02	1.947E+03	2.150E+02	2.759E+03	4.467E+02	5.733E+03
INT AGRI	6.818E+01	5.725E+02	9.437E+01	8.163E+02	1.389E+02	1.160E+03	2.886E+02	2.411E+03
YR = 400.								
INT CONS	8.558E+01	1.255E+03	1.220E+02	1.796E+03	1.735E+02	2.542E+03	3.604E+02	5.282E+03
INT AGRI	4.869E+01	5.168E+02	6.911E+01	7.392E+02	9.867E+01	1.046E+03	2.050E+02	2.175E+03
YR = 500.								
INT CONS	7.808E+01	1.183E+03	1.115E+02	1.693E+03	1.582E+02	2.396E+03	3.287E+02	4.978E+03
INT AGRI	4.336E+01	4.851E+02	6.175E+01	6.942E+02	8.781E+01	9.823E+02	1.825E+02	2.041E+03
YR = 1000.								
INT CONS	5.869E+01	9.769E+02	8.378E+01	1.398E+03	1.189E+02	1.979E+03	2.471E+02	4.112E+03
INT AGRI	3.112E+01	3.980E+02	4.427E+01	5.694E+02	6.301E+01	8.058E+02	1.309E+02	1.674E+03
YR = 2000.								
INT CONS	4.491E+01	8.264E+02	6.407E+01	1.183E+03	9.100E+01	1.674E+03	1.891E+02	3.478E+03
INT AGRI	2.251E+01	3.347E+02	3.195E+01	4.788E+02	4.556E+02	6.776E+02	9.466E+01	1.408E+03

*"YR =" means number of years following termination of the disposal facility license.

**"INT-CONS" means intruder-construction scenario.
"INT-AGRI" means intruder-agriculture scenario.

within the waste. For example, intruder-agriculture bone doses range across the 4 spectra from about 1.7 to 7.3 rems at 100 years but fall to a range of only 20 to 80 millirems at 500 years. In only 400 years, potential exposure levels drop by 2 orders of magnitude. Thereafter, the rate that potential exposure levels drop is much less significant--e.g., about a factor of two from 500 years to 1000 years and another factor of about two from 1000 years to 2000 years.

In addition, it may be observed that potential exposures generally increase from waste spectrum 1 to waste spectrum 4. For each successive waste spectra, a number of the waste streams are subjected to more extensive volume reduction techniques and increasingly improved waste solidification techniques are employed. For example, in waste spectrum 1 no special effort is made to compact trash. However, combustible trash is compacted in waste spectrum 2 and incinerated in waste spectra 3 and 4. As another example, ion exchange resins are assumed to be dewatered in waste spectrum 1, solidified in waste spectra 2 and 3, and calcined and solidified in waste spectrum 4. The increased use of volume reduction techniques on the waste streams results in an overall increase in the concentration of radionuclides in the disposal facility, leading to higher potential exposures. However, since it is not practical to subject all streams to extensive volume reduction, the total potential exposures only rises by a factor of four from spectrum 1 to spectrum 4. (Even under extensive volume reduction assumptions there are still a number of low activity waste streams which "dilute" the higher activity waste streams.)

The improved waste forms assumed from one spectrum to the next tend to help mitigate the effects of the increased radionuclide concentrations. In the no-credit case, the approximate factor of four difference is still observed in potential inadvertent intruder exposures between spectrum 1 and spectrum 4. However, the level of exposures for all four spectra is higher for the no-credit case than for the credit case. The rate at which potential exposures drop is also much less for the no-credit case than for the credit case. For example, the potential intruder-construction exposures at 500 years are about two orders of magnitude higher in Table 4.14 than in Table 4.13. This is due to the fact that initially, most of the potential exposures are from direct gamma radiation from such isotopes as Cs-137 or Co-60. Except for some additional self-shielding achieved by solidification in cement and the somewhat decreased radionuclide concentrations resulting from solidification, improvements in waste form have little effect on reducing the direct gamma radiation component of the calculated hazard. However, most of these potential gamma exposures would be caused by relatively short-lived isotopes, and as shown in Table 4.13, these decay after a few hundred years to relatively low levels.

As the shorter-lived gamma-emitting isotopes decay away, the most significant exposures are caused by longer-lived isotopes which generally contribute to the exposures through inhalation and food pathways. (An exception is Nb-94, which is a long-lived gamma-emitting isotope.) For example, exposures from I-129 or Tc-99 would be generally contributed through food pathways while exposures from transuranics would be generally contributed through inhalation pathways. The potential exposures from Sr-90, which is relatively short-lived (28-year half-life), would also be mainly contributed by the food pathway.

As a further illustration, Tables 4.15 and 4.16 are included which provide waste form credit example impacts for BWR ion exchange resins. Table 4.15 illustrates exposures to whole body and bone while Table 4.16 illustrates exposures to thyroid. Tables 4.15 and 4.16 may be compared against the respective waste form no-credit cases in Tables 4.4 and 4.5. Comparing Table 4.4 with Table 4.15, it appears that although some reduction in exposures for the waste form credit case are evident, the reduction is not particularly high. This is because exposures to whole body and bone are mainly dominated by direct gamma radiation, and the reduction in dispersibility and plant uptake illustrated by the waste form credit case (Table 4.15) has no effect on the radiation levels. Taking credit for waste form has more effect on potential exposures to the thyroid, since much of the thyroid exposure is due to ingestion of I-129 and reduced leaching would result in reduced uptake by plants. For waste spectrum 3, for example, calculated thyroid exposures after 400 years are reduced from the no-credit case by a factor of about 6.

Thus, the credit given to the waste form in reducing dispersion, inhalation, and plant uptake would appear to result in less significant reduction in impacts during the first few 100 years, but lead to reduced impacts over the next several hundred years. During the first few hundred years, the exposures are predominantly due to direct gamma radiation exposure from shorter-lived gamma-emitting nuclides. During the next few 100 years, the shorter-lived nuclides decay, and exposures are principally due to inhalation and ingestion of the longer-lived radionuclides. The actual values of the results are recognized to be uncertain, but do indicate that improved waste forms and packaging would help to reduce potential intruder exposures.

Before analyzing the cost and benefits of improved stable waste forms in detail, the need for placing wastes into stable waste forms and the long-term effectiveness of stable waste forms should first be evaluated. The need for placing wastes into stable forms is reviewed in the next subsection which addresses the second aspect of improved waste forms--i.e., the reduction in the likelihood of inadvertent intrusion.

4.3.4.3 Reduction in the Likelihood of Inadvertent Intrusion

The two intruder scenarios analyzed both contain one very large assumption--that the soil/waste mixture in which construction or agriculture takes place is more or less indistinguishable from dirt. That is, the waste has decomposed to the point that the intruder does not know he is contacting waste. This assumption is necessary since without it, the scenarios could not happen. Wastes currently being sent to disposal facilities cover a wide variety of forms and contained activities. About 60 percent of the volume of the waste in waste spectrum 1 that is assumed to be disposed in the reference disposal facility consists of miscellaneous trash which is relatively unstable in that it decomposes, degrades, and compresses rapidly. It is conceivable that after several hundred years, such wastes streams would be decomposed to the point where construction or agricultrual activities could take place without a potential inadvertent intruder realizing that something was wrong (i.e., that he was digging into something other than soil). In addition, such waste streams are unstable and their decomposition can lead to slumping and subsidence of disposal cell covers

Table 4.15 Potential Intruder Exposures to Whole Body and Bone for BWR Ion-Exchange Resins (Credit Case)

(mrem)

	Spectrum 1		Spectrum 2		Spectrum 3		Spectrum 4	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
REC CONS	6.196E+04	6.196E+04	3.004E+04	3.004E+04	3.098E+04	3.098E+04	5.576E+05	5.576E+05
REC AGRI	7.341E+04	7.354E+04	3.558E+04	3.560E+04	3.669E+04	3.669E+04	6.603E+05	6.604E+05
YR = 100.								
REC CONS	1.930E+04	1.930E+04	9.356E+03	9.356E+03	9.648E+03	9.648E+03	1.737E+05	1.737E+05
REC AGRI	2.286E+04	2.290E+04	1.108E+04	1.109E+04	1.143E+04	1.143E+04	2.057E+05	2.057E+05
YR = 150.								
REC CONS	6.085E+03	6.086E+03	2.951E+03	2.951E+03	3.043E+03	3.043E+03	5.477E+04	5.477E+04
REC AGRI	7.210E+03	7.223E+03	3.495E+03	3.497E+03	3.603E+03	3.604E+03	6.486E+04	6.487E+04
YR = 200.								
REC CONS	1.923E+03	1.923E+03	9.325E+02	9.326E+02	9.617E+02	9.617E+02	1.731E+04	1.731E+04
REC AGRI	2.279E+03	2.284E+03	1.104E+03	1.105E+03	1.139E+03	1.139E+03	2.050E+04	2.050E+04
YR = 300.								
REC CONS	1.989E+02	1.989E+02	9.642E+01	9.646E+01	9.943E+01	9.943E+01	1.790E+03	1.790E+03
REC AGRI	2.358E+02	2.373E+02	1.142E+02	1.145E+02	1.178E+02	1.179E+02	2.120E+03	2.120E+03
YR = 400.								
REC CONS	2.764E+01	2.770E+01	1.340E+01	1.344E+01	1.382E+01	1.382E+01	2.487E+02	2.488E+02
REC AGRI	3.299E+01	3.389E+01	1.591E+01	1.606E+01	1.637E+01	1.640E+01	2.947E+02	2.951E+02
YR = 500.								
REC CONS	1.060E+01	1.066E+01	5.142E+00	5.176E+00	5.300E+00	5.303E+00	9.540E+01	9.545E+01
REC AGRI	1.280E+01	1.353E+01	6.125E+00	6.245E+00	6.284E+00	6.307E+00	1.131E+02	1.134E+02
YR = 1000.								
REC CONS	8.532E+00	8.571E+00	4.137E+00	4.161E+00	4.265E+00	4.267E+00	7.667E+01	7.680E+01
REC AGRI	1.034E+01	1.089E+01	4.934E+00	5.025E+00	5.058E+00	5.075E+00	9.102E+01	9.126E+01
YR = 2000.								
REC CONS	8.213E+00	8.240E+00	3.982E+00	3.999E+00	4.106E+00	4.107E+00	7.390E+01	7.393E+01
REC AGRI	9.845E+00	1.042E+01	4.748E+00	4.826E+00	4.869E+00	4.884E+00	8.762E+01	8.782E+01

Table 4.16 Potential Intruder Exposures to Thyroid for BWR Ion Exchange Resins (Credit Case)

	(mrem)			
	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
YR = 50.				
INT CONS	6.196E+04	3.004E+04	3.098E+04	5.576E+05
ING AGRI	7.344E+04	3.558E+04	3.669E+04	6.604E+05
YR = 100.				
INT CONS	1.930E+04	9.356E+03	9.648E+03	1.737E+05
INT AGRI	2.292E+04	1.109E+04	1.143E+04	2.057E+05
YR = 150.				
INT CONS	6.085E+03	2.951E+03	3.043E+03	5.477E+04
INT AGRI	7.276E+03	3.505E+03	3.605E+03	6.490E+04
YR = 200.				
INT CONS	1.923E+03	9.325E+02	9.617E+02	1.731E+04
INT AGRI	2.347E+03	1.115E+03	1.141E+03	2.054E+04
YR = 300.				
INT CONS	1.989E+02	9.643E+01	9.943E+01	1.790E+03
INT AGRI	3.050E+02	1.247E+02	1.199E+02	2.158E+03
YR = 400.				
INT CONS	2.767E+01	1.342E+01	1.382E+01	2.488E+02
INT AGRI	1.022E+02	2.642E+01	1.854E+01	3.336E+02
YR = 500.				
INT CONS	1.063E+01	5.160E+00	5.302E+00	9.543E+01
INT AGRI	8.203E+01	1.664E+01	8.449E+00	1.521E+02
YR = 1000.				
INT CONS	8.563E+00	4.156E+00	4.266E+00	7.680E+01
INT AGRI	7.957E+01	1.545E+01	7.222E+00	1.300E+02
YR = 2000.				
INT CONS	8.245E+00	4.001E+00	4.107E+00	7.393E+01
INT AGRI	7.918E+01	1.526E+01	7.033E+00	1.266E+02

at the disposal facility, increasing rainfall percolation into the disposal facility, and further accelerating waste decomposition.

Other wastes, however, are composed of more stable material such as liquids solidified into concrete. If such wastes are indiscriminately mixed with compressible wastes, then it is conceivably possible that construction and agriculture activities could take place without the inadvertent intruder realizing that something was wrong. Such stable waste streams may be sufficiently dispersed through the waste that the presence of an odd lump or two would be ignored. In addition, a higher level of decomposition of the stable waste would be expected due to disposal of the stable waste with the unstable waste.

If, on the other hand, the stable wastes were segregated from the easily degradable wastes, then the potential for degradation of the stable waste would be greatly decreased. Even after several hundred years, the waste mass should still be clearly recognizable as something other than ordinary dirt. It is not credible to suppose that an individual would attempt to construct a house on or grow crops in a location characterized by large stacked metal cylinders filled with concrete. For such cases, exposures would be confined to those received during discovery of the disposed waste. Upon discovery, it is reasonable to expect that the intruder would cease operations while the matter would be investigated. As discussed below under institutional controls (Section 4.3.8), all knowledge about a disposal facility should not be lost and information about the facility would be assessed in determining a proper course of action with respect to the inadvertent intruder. If the individual chose to ignore information about the facility, the event would no longer be considered inadvertent intrusion.

Potential inadvertent intruder hazards were calculated for the base case based upon an assumption that all waste streams are randomly mixed together during disposal. Due to the slumping, subsidence, and higher infiltration that would be associated with this disposal practice, rapid waste degradation could occur. As just discussed, however, if the wastes were placed into a stable form or package and were also segregated and disposed of in separate disposal cells so that waste degradation would be minimized, then the likelihood of inadvertent intrusion would be greatly reduced. It is not credible to suppose that such activities as housing construction or gardening could take place under these conditions since the inadvertent intruder would contact hunks of waste and realize that something is wrong. Potential exposures would be limited to those received during discovery of the waste. As an illustration, Table 4.17 may be compared with Table 4.18. Table 4.17 was prepared by removing the decontamination resin and sources waste streams (L-DECONRS and N-SOURCES) and dividing the remaining 34 streams into two groups: a "high activity" group and a "low activity" group. The high activity group is composed of LWR process wastes (group 1), PWR and BWR noncompactible trash, and the remaining 5 waste streams in group 4. Waste spectrum 2 is assumed, for which all of the waste streams in the high activity group have been placed into a stable form which will resist rapid decomposition. The low activity group is composed of the

Table 4.17 Potential Hazard to Whole Body and Bone for Two Groups Without Segregation for Waste Spectrum 2

	Waste Form Credit Case				Waste Form No-Credit Case			
	High Activity Group		Low Activity Group		High Activity Group		Low Activity Group	
	Body	Bone	Body	Bone	Body	Bone	Body	Bone
YR = 50.								
INT CONS	1.142E+04	1.142E+04	9.824E+01	9.862E+01	1.143E+04	1.147E+04	9.833E+01	9.930E+01
INT AGRI	1.537E+04	1.363E+04	1.322E+02	1.576E+02	1.571E+04	1.501E+04	1.326E+02	1.586E+02
YR = 100.								
INT CONS	3.464E+03	3.464E+03	2.989E+01	3.004E+01	3.467E+03	3.491E+03	2.994E+01	3.050E+01
INT AGRI	4.219E+03	4.138E+03	3.879E+01	4.815E+01	4.317E+03	4.546E+03	3.887E+01	4.858E+01
YR = 150.								
INT CONS	1.094E+03	1.094E+03	9.456E+00	9.530E+00	1.095E+03	1.113E+03	9.485E+00	9.912E+00
INT AGRI	1.304E+03	1.309E+03	1.224E+01	1.565E+01	1.333E+03	1.433E+03	1.227E+01	1.589E+01
YR = 200.								
INT CONS	3.470E+02	3.471E+02	3.020E+00	3.072E+00	3.481E+02	3.632E+02	3.043E+00	3.412E+00
INT AGRI	4.120E+02	4.172E+02	4.011E+00	5.596E+00	4.208E+02	4.582E+02	4.029E+00	5.774E+00
YR = 300.								
INT CONS	3.763E+01	3.775E+01	3.526E-01	3.935E-01	3.847E+01	5.100E+01	3.717E-01	6.849E-01
INT AGRI	4.470E+01	4.669E+01	6.289E-01	1.500E+00	4.578E+01	5.544E+01	6.410E-01	1.640E+00
YR = 400.								
INT CONS	6.894E+00	6.998E+00	8.690E-02	1.238E-01	7.614E+00	1.862E+01	1.037E-01	3.826E-01
INT AGRI	8.216E+00	9.161E+00	2.932E-01	1.086E+00	8.611E+00	1.441E+01	3.039E-01	1.210E+00
YR = 500.								
INT CONS	3.810E+00	3.904E+00	5.958E-02	9.376E-02	4.450E+00	1.434E+01	7.455E-02	3.268E-01
INT AGRI	4.546E+00	5.048E+00	2.570E-01	1.030E+00	4.850E+00	9.478E+00	2.669E-01	1.143E+00
YR = 1000.								
INT CONS	3.336E+00	3.400E+00	5.302E-02	7.902E-02	3.740E+00	1.041E+01	6.247E-02	2.333E-01
INT AGRI	3.973E+00	4.084E+00	2.384E-01	9.597E-01	4.172E+00	7.013E+00	2.458E-01	1.040E+01
YR = 2000.								
INT CONS	3.171E+00	3.213E+00	4.988E-02	7.011E-02	3.411E+00	7.879E+00	5.543E-02	1.692E-01
INT AGRI	3.776E+00	3.861E+00	2.149E-01	8.531E-01	3.907E+00	5.838E+00	2.204E-01	9.092E-01

remaining 20 waste streams, including the remaining trash streams and the streams composing group 3. The low activity stream is composed of compressible waste forms which easily degrade and can lead to trench subsidence. Table 4.18 shows the potential hazard of the same high activity waste assuming that it is disposed of in a segregated manner from the low activity group. In this case, the intruder-agriculture scenario does not occur and the hazard is calculated based upon a small number of hours during which the inadvertent intruder is exposed through the assumed discovery scenario. Comparing Table 4.17 with Table 4.18, the difference in potential impacts is striking.

Table 4.18 Potential Hazard to Whole Body and Bone for High Activity Group with Segregation (Waste Spectrum 2)

	Waste Form Credit		Waste Form No-Credit	
Year	Body	Bone	Body	Bone
50	1.37E+2	1.37E+2	1.37E+2	1.38E+2
100	4.16E+1	4.16E+1	4.16E+1	4.19E+1
150	1.31E+1	1.31E+1	1.31E+1	1.34E+1
200	4.16E+0	4.17E+0	4.18E+0	4.36E+0
300	4.52E-1	4.53E-1	4.62E-1	6.12E-1
400	8.27E-2	8.40E-2	9.14E-2	2.23E-1
500	4.57E-2	4.68E-2	5.34E-2	1.72E-1
1000	4.00E-2	4.08E-2	4.49E-2	1.25E-1
2000	3.81E-2	3.86E-2	4.09E-2	9.45E-2

The costs and impacts of placing the higher activity wastes into a stable form and disposing of them in separate segregated disposal cells is analyzed in detail in Chapter 5 as well as other alternatives evaluated by NRC to achieve long-term stability. Rather than repeating the analysis here, the reader is referred to Chapter 5.

4.3.4.4 Effectiveness of Stable Waste Form

One last issue remains--i.e., how long is it necessary to rely on the stable waste form?

If the disposal cell is stabilized so that minimum infiltration is introduced to the disposal cell, then the waste form should be effective against intrusion for several hundred years. It is not reasonable, however, to expect this to be the case indefinitely. From Table 4.18 one can see that after several hundred years (i.e., on the order of 500 years), most of the shorter-lived radionuclides will have decayed away, leaving the longer-lived radionuclides. The reduction in hazard after 500 years takes place at a much slower rate. It would appear, then, that for most wastes, a limit of 500 years would appear to be the maximum reasonable upper bound. Attempting to reduce intruder impacts through waste form beyond 500 years would for most wastes really not accomplish much in the way of additional protection. In addition, the period of time upon which institutional controls are relied upon will also effect the long-term stability of waste. After institutional control ceases a higher rate of infiltration into disposal cells could occur leading to an increased rate of waste decomposition.

4.3.5 Engineered and Natural "Intruder Barriers" Created Through Facility Design and Operations

Another method by which the hazard to a potential intruder may be reduced is to dispose of the waste in a manner that would make it more difficult for a potential intruder to contact the waste--that is, by placing one or more natural or engineered barriers between the waste and the intruder. The majority of the waste streams that could require disposal by methods that provide protection against inadvertent intrusion would probably also be characterized by high surface radiation levels. Some wastes having high surface radiation levels may be dominated by short-lived isotopes, and therefore may not be of significant concern to a potential future inadvertent intruder. However, the temporarily high radiation levels associated with such wastes would still require additional care during waste handling and disposal operations. It is useful, therefore, to consider a number of potential waste disposal concepts which may offer increased protection against the actions of a potential inadvertent intruder, while at the same time offer increased worker radiation protection during waste handling and disposal operations.

Typically, only a small fraction (about 10%) of the packages received at commercial radioactive waste disposal facilities would be characterized by elevated exposure rates (e.g., greater than 5 R/hr). These wastes pose some restrictions on operations at disposal facilities. At the present time, most high exposure rate ("hot") waste is dealt with on a case-by-case basis. For example, optimal locations for shielding in trenches are often reserved for high exposure rate waste packages. Optimal locations in trenches can include corner locations and positions between waste packages having low activity levels. Additionally, rapid partial backfilling of high exposure rate packages may be employed to reduce radiation levels to acceptable working levels.

Special "hot" waste disposal cells have been employed from time to time at some of the commercial disposal facilities, as well as at some of the U.S. Department of Energy radioactive waste disposal facilities. The types of disposal cells that have been employed for disposal of high exposure rate waste packages have included slit trenches, caissons, reinforced concrete culvert pipes, concrete walled trenches, auger holes, and toner tubes (a specific type of caisson with a basket funnel for introducing waste packages). These disposal cells serve to provide shielding protection from the high radiation fields associated with hot waste packages.

NRC analyzed a number of such potential barriers to an intruder and these are described in detail in Appendix F. The barriers considered and additional costs are shown in Table 4.19. These costs are for facility design and operation and do not include costs for long-term care. In general, the barriers can be grouped into three major categories as follows:

Table 4.19 Summary of Incremental Barrier Costs For Facility Design and Operation

	Additional Disposal Costs		
Type of Barrier	$/m³	$/ft³	Note
No barrier	0	0	*
Thicker cap - 3m of soil	1.59	0.05	*
Thicker cap - 3m of compacted clay	10.89	0.31	*
Layered waste disposal	37.73	1.07	**
Slit trench (10% of waste)	91.49	2.59	**
Caisson disposal (10% of waste)	216.45	6.13	**
Walled trench (10% of waste)	256.09	7.25	**
Walled Trench (100% of waste)	160.99	4.56	*
Grouting--cement†	60.46	1.71	*
Grouting--low-strength cement†	46.86	1.33	*
Engineered intruder barrier	59.17	1.68	*
Intermediate depth burial	53-159	1.50-4.50	*
Mined cavity	327-654	9.26-18.52	*
Ocean disposal	710-2200	20.11-62.31	*
Space disposal	2E+6	56,600	*

*Unit costs based upon 1,000,000 m³ of waste disposed.

**Unit costs based upon volume of waste disposed by the disposal method indicated. For this table, the costs are based upon a volume of about 100,000 m³.

†Unit costs include additional costs for stacked waste emplacement.

1. Engineered barriers including caisson disposal, walled trenches, grouting, and a special "engineered intruder barrier"; and

2. Depth of disposal including thicker trench caps, layered waste disposal, and slit trenches;

3. Other methods of disposal including intermediate depth burial, mined cavities, ocean disposal, and space disposal.

An important consideration for these and other forms of intruder barriers is whether the barriers are needed. As discussed previously, most waste streams contain relatively low levels of activity while some contain relatively high levels of activity. It would not appear to be justified to require that all waste streams would require disposal using a barrier to an intruder. For most waste streams, the potential hazard falls off rapidly with time, e.g., to levels on the order of a few millirems or less after a few hundred years. Thus, the use of such barriers would only be required for the higher activity waste streams.

4.3.5.1 Engineered Barriers

The engineered barriers analyzed included the use of caissons, walled trenches, grouting, and the use of a specially engineered intruder barrier. Caissons and walled trenches are examples of the use of "engineered structures" for waste disposal. Other possible engineered structure designs have been examined elsewhere (Ref. 8).

Each engineered barrier is described below. In general, the engineered barriers can provide an effective deterrent to an inadvertent intruder, but at relatively high cost.

Caisson Disposal

To represent the estimated costs and anticipated benefits of use of caissons, tubes, and reinforced concrete pipes for disposal of high activity waste, an example case employing reinforced concrete pipes is evaluated. In the illustrative example presented in Appendix F, each such "hot" waste disposal cell is assumed to consist of a 30-in (0.6 m) inside diameter reinforced concrete culvert pipe which is 24 ft (7.3 m) in length. These culvert pipes are inserted vertically into a slit trench which is 15 m (50 ft) in length, 1.5 m (5 ft) in width, and 8 m (26 ft) in depth.

Each slit trench can accommodate 16 of the reinforced concrete culvert pipes, which can accommodate either 55- or 83-gallon drums. Larger diameter pipes would be used for larger waste packages. As a result of the lower potential for slope failure resulting from the lateral structural support provided by the culvert pipes and the shielding provided by the concrete, the inter-trench spacing can be reduced. Therefore, each slit trench is assumed to be separated from adjacent trenches by a minimum of 1 m (3.3 ft). This results in an overall land use efficiency which is about 60 to 65% of the efficiency attained for the reference trenches (180 m x 30 m x 8 m) described in Appendix E.

In the example, costs are estimated for disposal of 10% of the waste received at the disposal facility being disposed through caisson disposal. The estimated cost differential for this option is about $216/m³ ($6.13/ft³). These costs were calculated assuming that no shoring was used to construct the caisson trenches. If such shoring were required, unit differential costs would be higher. The reduction in occupational dose afforded by this option is probably similar to that estimated for the slit trench case described below (10 to 20%).

Concrete-Walled Trench Disposal

A second type of "hot waste" disposal cell which has been employed for selected wastes in foreign countries (e.g., Chalk River, Canada) is the concrete-walled trench. For illustrative purposes, a concrete-walled trench is assumed to be constructed of reinforced concrete and to have inside dimensions of 12 m length, 3 m width, and 7 m depth. The wall thickness of the walled trench is assumed to be 0.3 m (1 ft). The dimensions of these walled trenches can be increased to be able to handle larger-sized waste packages. The walled trenches described here are capable of handling 55- and 83-gallon drums, large wooden boxes, and steel liners. All void spaces between emplaced waste packages may be filled with earth or, for increased stability and intruder protection, by a controlled density fill such as concrete or grout. Filled trenches are covered by a 1 m thick concrete cap followed by a layer of overburden graded for drainage.

The spacing between walled trenches is assumed to be a minimum of 3 m as a result of the requirements for concrete forming work. Due to the larger spacing required for this type of disposal cell and the volume lost by the wall displacement, the land use efficiency disposal cell is calculated to be less than 25% of that for the reference trench.

Differential costs are estimated for (1) an example in which 10% of the waste volume delivered to the disposal facility is assumed to be disposed in concrete walled trenches, and (2) an example in which 100% of the waste is disposed in concrete walled trenches. These differential costs are calculated in Appendix F to be about $256/m³ for the former example, and about $161/m³ for the latter example. Effects of economics of scale are apparent. Additional land use for the two examples are, respectively, 4.1 acres and 39.5 acres. Costs (for 10%) of waste disposed are seen to be higher than the caisson trench example; however, less additional land is required.

Grouting

Grouting and the use of controlled density fill would generally significantly discourage most potential intruders, although the ability to excavate controlled density fill is higher than that for regular cement. The use of low-strength cement (at a cost of $47/m³) would offer intruder protection but not as much as higher-strength cement at a cost of $60/m³. (Unit costs include costs for stacked waste emplacement.) The waste would need to be placed in layers after which each layer would be grouted. Additional time would also be required to carry out grouting operations.

Engineered Intruder Barrier

The construction of an engineered barrier to the intruder would also significantly discourage most potential inadvertent intruders. For purposes of analysis, NRC assumed such a barrier would consist of multiple layers of different materials placed on top of the waste which would provide both depth in excess of that associated with most construction and agricultural activities as well as materials such as asphalt, concrete, and cobbles that would need to be removed at a relatively high cost to carry out such activities. The cost for such a barrier is high ($59/m^3$) and it would be difficult to maintain if subsidence were a problem because of the multiple layers of various materials.

4.3.5.2 Depth of Disposal

The most obvious barrier is depth of disposal. Placing the waste at greater depths would be expected to remove it from most of man's near-surface activities. For example, raising the thickness of the cap to approximately 3 meters would result in a thickness of approximately 4 m between ground surface and the top of the disposed waste. The alternatives considered included thicker trench caps, layered waste disposal, and slit trenches.

Thicker Disposal Cell Covers

One alternative which may be used to minimize the potential for intrusion is simply to increase the thickness of the cover over the disposal cells.

At the reference disposal facility, the waste is assumed to be emplaced to a level approximately one meter below the top of the trench. This one meter space is filled with overburden, and a cap is then emplaced which is also assumed to be one meter thick. This results in approximately 2 meters (6.6 ft) of earth between the top of the waste and the surface of the ground. This thickness of cover would probably preclude contact of the waste through most potential agricultural activities, but may still allow partial contact through such activities as construction of a basement for a house.

An additional 3 meters of overburden would raise the distance between the waste and the ground surface to about 5 meters (16.4 ft). The thickness would place the top of the disposed waste about 2 meters below the level that typical basements would be constructed (about 3 m). An earthen thickness of 3 to 5 meters would also be expected to place the waste below typical burrowing depths of many burrowing insects and animals, as well as below the root depths of many plant species--particularly many food crops.

At existing disposal facilities, disposal trenches are excavated, filled with waste, covered over with previously excavated soils, and capped. There is usually considerable excess dirt from trench excavation and this dirt is generally applied as additional overburden over the trench cap. Existing disposal facilities often have as much as 2.4 to 3.7 m (8 to 12 feet) of earth separation between the top of the disposed waste and the surface of the earth.

Based upon the assumption that additional costs for fill royalties, hauling, spreading, and compaction efforts will be accrued, it is estimated that increasing the thickness of the trench cover by 3 meters will result in an increased operational cost of about $11/m^3$ of waste ($0.31/ft^3$). This figure is based upon the assumption that the additional fill is obtained from a clay borrow area located 10 miles offsite. The cost could be substantially reduced if the additional fill is obtained from excess excavated earth. In this latter case, additional design and operational costs would be reduced to about $2/m^3$. Of course, the clay cap provides greater protection against percolation into the disposed waste, resulting in reduced waste decomposition and lowered ground-water migration.

In a similar vein, an increased distance between the ground surface and the top of the disposed waste could be achieved by increasing the thickness of earthen material between the top of the waste and the top of the trench. For example, if only the bottom 4 m out of the 8 m excavation were used for waste disposal, the thickness of material between the waste and the top of the trench cap would be increased to 5 m (16.4 ft). The reduction in potential intruder impacts would be equivalent to the case described above regarding increased overburden thickness, but would be brought about by decreased land use efficiency. If at the reference disposal facility only the bottom 4 m (instead of the bottom 7 m) of all disposal trenches were used for waste disposal, then the land use efficiency would be dropped from 2.9 m^3/m^2 to approximately 1.6 m^3/m^2. The land area committed to waste disposal would be raised from 87 acres to about 105 acres, and the number of disposal trenches constructed raised from 58 to 105. Due to the additional amount of trench construction, filling, grading, seeding, and other groundskeeping activities that would be performed, costs would be proportionately raised (by about $5/m^3$).

Layered Waste Disposal

Protection against inadvertent intrusion may be accomplished by layering of the waste according to the relative hazard of the waste. The concept of trench layering involves placement of wastes having a higher potential hazard along the bottom of the trench with wastes having a lower potential hazard emplaced on top. Typically, higher potential hazard waste generally would include waste packages characterized by high surface radiation levels or wastes that could pose a significant airborne hazard if disturbed by excavation.

Layered waste disposal would use the same trenches described in the reference disposal facility (Appendix E). In the reference facility trench, only the bottom 7 m out of the 8 m excavated is used for disposal of waste. For layered waste disposal, the bottom 2 m (6.6 ft) of the excavation is assumed to be used for disposal of higher potential hazard waste material. The remaining 3-5 m of available space is used for disposal of lower potential hazard waste material. Thus, the inadvertent intruder would have to dig through 2 m of backfill and 3-5 m of lower hazard waste before encountering waste that could result in a significant potential exposure. Excavation work that uncovered boxes and drums of low activity waste would probably discourage further excavation long before the more hazardous material were reached. Layered waste disposal would also help to reduce personnel exposures during disposal operations, by providing additional shielding for wastes having high gamma radiation levels.

The option of layered waste disposal would not appreciably alter design, operations or labor requirements. However, there would have to be an adequate mix of lower hazard to higher hazard waste on hand to allow for successful implementation of the option (i.e., a lower hazard waste to higher hazard waste volume ratio of about 2.5 to 1 or greater). Maintaining an input of waste at this ratio could on occassion require either careful scheduling of input from waste generators, and/or implementing greater storage capability at the site. It might also be necessary to have the capability of transporting the waste from a site waste storage area. Therefore, operational changes at the disposal facility might involve temporary storage of waste, additional coordination of waste receipt and emplacement, and transport of stored waste from the storage area to the disposal trench. The only significant operational cost differences would include possible construction of an inexpensive moderately sized waste storage facility (e.g., an open-sided roofed structure intended to provide some weather protection for the stored wastes, and perhaps a storage pad with tarpolins for large packages), and the aquisition of an onsite transport vehicle (e.g., a flatbed truck). Since these high activity wastes also present greater potential for migration and the need for greater stability over the long-term as discussed in Chapter 5, the lower activity wastes used for layering should also be in a stable, noncompressible form. The estimated cost differential for this option is about \$38 per m^3 of waste requiring layered disposal. No additional land would be committed to waste disposal.

Slit Trench Disposal

A slit trench typically has a length dimension which is more than 5 times the width dimension (width dimension is generally less than 5 meters). The assumed dimensions of vertical-walled slit trenches in this EIS are 20 m in length, 3 m in width, and 8 m in depth. The minimum spacing employed between slit trenches is assumed to be 2 m. The assumed disposal efficiency is 50%, which means that only 50% of the total available void space is eventually occupied by waste packages.

It is assumed that 10% of the waste volume received at the facility will require disposal using slit trenches. The assumed slit trench dimensions and spacing imply that the land use efficiency of slit trench disposal is approximately half the efficiency of the reference trenches (180 m x 30 m x 8 m) described in Appendix E (or about 4.7 ft^2/ft^3). The anticipated cost differential between the base case unit disposal cost and the near-surface disposal facility employing slit trenches for "hot" waste is about \$91 per m^3 of waste disposed into slit trenches. This cost is calculated assuming that no shoring is used during slit trench construction and waste emplacement. If shoring were used--either to allow construction work inside the slit trenches or to maintain side walls during waste emplacement--then unit costs for slit trench operations would be considerably higher.

The slit trench option results in an additional 2.8 ha (7 acres) committed to waste disposal. The overall land use efficiency for this option is estimated to be 8.75 ft^3/ft^2 (mixture of regular and slit trenches). The major anticipated benefit of employing this option is a reduction in the occupational exposures received by the waste emplacement labor force at the disposal facility. It is estimated that the use of slit trenches can possibly reduce occupational exposures by between 10 and 20%. Use of slit trenches for high activity wastes would be expected to reduce potential intruder exposures by a factor of about two. A drawback to the use of these slit trenches are the moderate slope failure hazards existing for vertical-walled trenches. In addition, the restricted width dimensions of slit trenches may preclude the burial of very large waste packages.

4.3.5.3 Other Methods of Disposal

Since this EIS is limited to near-surface disposal, NRC did not analyze in detail other methods of disposal. Other methods of disposal, however, such as intermediate depth burial, mined cavities, and ocean and space disposal can be very effective against intrusion. For example, use of a mined cavity would place the waste several hundred meters below the surface of the earth--far below most activities of man. Space disposal removes the waste entirely from the earth's surface. However, both options are very expensive--i.e., $500 to $840 per cubic meter for mined cavity disposal (not including postoperational costs) and $2 million/$m^3$ for space disposal. In the case of space disposal, the technology for routine implementation of this option is not available at the present time and the potential hazards are unknown. Therefore, if space disposal were required for all low-level waste, then large quantities of low-level waste would need to be stored until the technology was fully developed. This would be extremely expensive to licensees.

Waste can also be disposed of at much deeper depths. The opportunities for doing so may be limited at most eastern disposal sites, and an intermediate depth disposal facility at a western site (an unused open-pit mine) is illustrated in Appendix F as an example. This is expected to be effective against potential intrusion but could also be expensive. The reader is referred to Appendix F for further information. With respect to mined cavity disposal, there are currently no mined cavity disposal facilities licensed to operate in the country. If all low-level waste were required to be disposed of by this method, then all waste currently being generated would have to be stored until mined cavity facilities were licensed.

4.3.6 Institutional Controls

Another mechanism for reducing potential impacts to a potential inadvertent intruder is use of institutional controls.

4.3.6.1 Background

Institutional controls are controls which require performance of some action by a governmental agency to preclude human contact with the waste, or require a continuing social order. Examples include the following:

- Access to a disposal site can be controlled to restrict entry. For example, the site can be surrounded by a fence or other barrier to human or livestock intrusion. This barrier can be posted with warnings not to intrude upon the site. In addition, the site can be under routine surveillance by regulatory and/or law enforcement agencies to assure continued integrity of the fence and to inspect for possible disturbance.

- Controlled productive use of the site surface--for example, construction of a golf course--can be carried out under regulatory agency licensed control. In such instances, access to the site can be patrolled or otherwise restricted by those licensed to use the site. Controlled productive site use could also result in income which may partially off-set administrative costs incurred by the licensed custodial agency.

- Periodic inspection of the disposal site and monitoring for potential ground-water releases can be performed by a regulatory or other governmental agency. (The act of monitoring and inspection necessarily implies an understanding of the potential hazards contained within the site.)

This period of time can be termed a period of active observation. Gradually, however, such active means of institutional controls are anticipated to decrease. The interval between inspections lengthens. As regulators move on to other concerns, gradually less time and effort is placed upon surveillance and control of a particular site.

Ultimately, institutional controls must also rely upon relatively passive means involving some manner of social order. The types of controls which would be relied upon during this passive control period can include the following:

- The location of the disposal facility as well as the location of specific disposal areas on the facility can be referenced to USGS benchmarks. Long-lasting monuments can be emplaced which contain an inscription describing the nature of the hazard.

- The location and configuration of the disposal facility, together with a description of the hazard, can be inexpensively recorded and maintained in a number of different locations on a local, county, state, and national level. This redundancy in recordkeeping would help to ensure that knowledge of the disposal facility would be retained.

- Control of the disposal facility site can be maintained by a responsible government body--that is, the federal government or the government of the state in which the site is located. Government ownership of the land minimizes the potential for possible abandonment of the site. State or federal ownership is already a requirement in existing NRC regulations in 10 CFR Part 20.

- The title to the disposal site (the deed) can contain a convenant which specifically warns of the potential hazard and specifies a restriction on the use of the land.

Probably the most significant concepts for long-term passive institutional control measures are those of control of the land by a governmental organization, land-use restrictions in the form of titles or deeds, and multiplicity of records. As civilizations have evolved over the centuries, societies have characteristically erected superstructures (governments) to perform services--for example, protection of life, health, and property--which are less conveniently performed by individuals. Among the function performed by governments are control of titles to and uses of property. Placing the long-term control of a disposal site into the hands of a government organization helps to ensure that such motivies as profit and loss do not lead to possible abandonment of the property, or sale for inappropriate uses.

Certain governmental functions, such as tax collecting, land controls, and an interest in the health and welfare of the society, are independent of the type and form of government involved. Whether the government is capitalistic or socialistic, democratic or autocratic, use of land is controlled for what is perceived to be the maximum benefit of the society. From time to time societies have altered (or have had alterations performed by outside means) their type and form of government by peaceful or violent means. Yet, these societies have merely changed the form of the government, not eliminated government altogether. The government may change but the institution of government does not change. Germany, for example, has within the last 60 years undergone a number of upheavals resulting in radical changes in its government. During these upheavals, temporary breakdowns in several governmental functions have occurred. However, such functions were relatively quickly resumed by the newly established governments.

In the system familiar to Western culture, land may be owned by a government, an individual, or an organization. Title to the land is expressed through deeds--which often contain restrictions or specifications on the use of the land. Legal restrictions and administrative requirements (for example, records) are imposed upon the ownership and transfer of the land. On a number of occasions, title for a particular property has remained in the same hands--that is, by a family, an organization, or a government--for several centuries.

Similarly, the title to a piece of property may change hands, but the use of the land for a particular purpose (for example, cemeteries) will remain essentially the same for very long time periods. Even for land owned and used collectively, some organization controls the title to and prescribes the use of the land. The land is used for a specified purpose (for example, farming) by a particular group of people, and the land futhermore has boundaries.

The principle of government control of a near-surface disposal facility site does not preclude productive use of the land. The surface of a near-surface disposal facility, for example, can probably be used in perfect safety, as long as the users of the land are precluded from excavating deeply into the subsurface. Indeed, controlled use of the land may be potentially encouraged as a means to collect revenues to off-set the administrative costs of exercising control.

Markers on disposal cells which provide an approximate quantification of the hazard of disposed waste can also provide a passive warning to future generations that something out of the ordinary has occurred at the site. The use of such markers is current practice at all existing disposal facilities. Typically at current sites, a disposal trench will be marked with a monument inscribed with at least the following information:

- Total activity of radioactive material, in curies, excluding source and special nuclear materials; total amount of source material in kilograms; and total amount of special nuclear material, in grams, in the trench;
- Date of filling and capping the trench; and
- Volume of waste in the trench.

Typically, the information is inscribed upon a metal plate which is mounted onto a stone. In addition, marker stones are frequently used to denote the corners of a disposal trench. Costs for such markers have been included in the costs for the reference disposal facility.

4.3.6.2 Limitations to Institutional Controls

Institutional controls such as those outlined in the preceding section can be used to protect against the actions of an inadvertent intruder. However, such institutional controls are effective only insofar as they last. Markers and monuments established at a disposal site may be stolen or defaced and the nature of the hazard may be buried in forgotten governmental files. Land-use restrictions may be potentially ignored or a future government bureaucracy may simply mistakenly release a site for inappropriate use.

It is probably not realistic, however, to assume that institutional controls would be completely lost for extended time periods. It is certainly not credible to assume that all knowledge of a disposal facility would be lost. As previously discussed, records of the disposal facility, including the precise locations of waste disposal cells referenced to a bench mark, may be maintained in a number of separate locations. In addition, the general location of a disposal facility would likely be maintained in any number of other records. The locations of existing disposal facilities have been described in literally thousands of newspaper and magazine articles, professional journals, and private- and government-published documents.

Taking all possible passive control measures together, it seems reasonable to expect that institutional controls may be reasonably effective indefinitely. As stated earlier, there are a number of examples of property ownership or control by an institution or organization for centuries. However, during this time period, there is a possibility of one or more occurrences where institutional controls may break down, leading to inappropriate use of the site and potential human exposures. In the extreme, such occurrences may include such activities as construction of a housing development, as was the case at Love Canal. (At Love Canal, however, houses were not constructed directly into disposed waste. Human contact with the disposed waste was caused by leaching of contaminants out of the disposed waste by ground water and movement of the contaminants through the ground water and into areas inhabited by humans).

Compared to other types of potential environmental hazards, radiation is comparatively easy to detect. Furthermore, techniques to detect radiation are certain to become more sophisticated as time goes by. Future societies will undoubtedly continue to have organizations which are concerned with the health and well-being of the society's citizens. Any type of environmental, social, or warlike event that would completely eliminate all consideration of the public health and safety (and of instruments to detect potentially harmful radionuclides) would be so calamitous in nature that the potential impacts from the disposal facility would be entirely secondary.

In addition, it is likely that if someone sometime in the future did excavate into a near-surface disposal facility site, it would occur to the person that something was out of the ordinary and he would take steps to investigate the situation. A scenario that someone may excavate into disposed waste and grow vegetables on the exposed waste necessarily incorporates a somewhat farfetched presumption that all of the waste is sufficiently decomposed so that it is homogeneously mixed with soil. As discussed earlier, as long as the waste is in a stable waste form, then extensive construction or agricultural activities are not considered credible. Even under conditions of rapid decomposition of wastes which are disposed in an unstable form, extensive construction or agricultural activities must be considered unlikely.

Still, accidents happen, and it is reasonable to assume that, after a given period of time after disposal, some temporary breakdown in institutional controls may lead to an inadvertent use of a closed disposal facility which leads to potential exposures to a few individuals. As in the case of Love Canal, this could happen not because of a conscious decision to ignore public health and safety, but because someone simply made a mistake.

The maximum time period for which active institutional controls can be relied upon to preclude inadvertent intrusion has been investigated by a number of people (Refs. 1-5, 9). In EPA's "Proposed Criteria for Radioactive Wastes, Recommendations for Federal Radiation Guidance," (as published in the Federal Register in November 1978 (43 FR 53262) (Ref. 9)), EPA proposed that a limit of 100 years should be used as a limit for the length of institutional controls. This limit was proposed based upon consideration of public input received at a number of public forums on radioactive waste disposal held by EPA.

In various studies exploring ways in which to classify radioactive waste for disposal, different institutional control periods have been used (Ref. 1-5). The institutional control periods assumed in these studies were all less than a few hundreds of years and ranged in these studies from 100 to 200 years.

The maximum time period that should be assumed for active institutional controls was discussed extensively at a series of 4 regional workshops held on the preliminary draft of the Part 61 rule. These workshops were held in Atlanta, Georgia; Denver, Colorado; Chicago, Illinois; and Boston, Massachusetts. A more detailed summary of these workshops is contained in Appendix C. The general consensus of these workshops was that a 100-year limit for active institutional controls was appropriate. NRC also quantitatively analyzed varying periods of active institutional control ranging from 50 to 300 years. This analysis was performed concurrently with that leading to selection of the preferred performance objective and is described in Section 4.5.

4.4 CONCLUSIONS AND COMPARATIVE EVALUATION OF ALTERNATIVES

In summary, there are many potential methods which could be implemented to reduce potential exposures to an inadvertent intruder. All methods would involve increased costs for disposal--some significantly. In addition, many waste streams contain very small quantities of radioactivity and it would not appear to be reasonable to require the additional expense for all waste streams, particularly considering the hypothetical nature of the intrusion scenarios. Some criteria--preferentially based upon a dose level to a few individuals--is needed to distinguish between waste streams which should be disposed with additional protection against potential intrusion and those waste streams for which this would not be necessary. Such a dose level would also establish the level of safety to assure protection of an inadvertent intruder--i.e., a performance objective for intrusion.

It also appears that for most cases, simply layering the disposed wastes would provide sufficient protection to an intruder. For some streams perhaps even more additional protection would be needed--for example, use of a walled trench. Finally, some waste streams may not be suitable for near-surface disposal.

In determining which waste streams may not be acceptable for near-surface disposal, one of the key questions is how long barriers to a potential intruder may be expected to last. Such barriers, of course, would be expected to last several hundred years but not forever. Some barriers may last longer than others. For example, the effectiveness of a "hot waste facility" (walled trench) discussed above to deter the actions of a potential intruder could be expected to last longer than the intruder barrier provided by layering. As discussed above, the "hot waste facility" is assumed to consist in this EIS of a disposal trench which has a 0.3 m thick concrete base, 0.3 m thick concrete walls, and a one-meter thick concrete cap. This trench may be then covered over with fill.

From the analyses performed for this EIS, it can be seen that due to radioactive decay, exposures to a potential inadvertent intruder from almost all waste streams typically considered to be LLW fall to a few millirems after a few hundred years--e.g., 500 years. After 500 years, only a few waste streams are estimated to result in potential intruder exposures of a few hundred millirems. Very few (e.g., one or two) streams having small volumes are estimated to result in potential intruder exposures exceeding 500 mrem after 500 years. A time period of 1,000 years was assumed for a "hot waste facility" to provide an upper estimate of the degree to which near-surface disposal techniques can reduce potential intruder exposures.

On the other hand, waste streams that are generally considered to be "high-level waste" (e.g., spent reactor fuel, solidified first solvent extraction stages from a nuclear fuel reprocessing plant) contain much higher initial levels of radioactivity. Typically, the potential hazard from high-level waste disposal is dominated by fission products over approximately the first 600 years. After that approximate time period, most of the fission-product activity has decayed, except for iodine-129 and technetium-99; radioactivity is dominated thereafter by the actinides--e.g., U, Np, Pu, Am, Cm and their daughters.

This point was recognized by NRC during development of the regulation 10 CFR 60 for geologic disposal of high-level waste. In the Federal Register Advance Notice of Proposed Rulemaking on this rule (Ref. 10), there was included a draft requirement that high-level wastes should be placed into a canister that would last for 1,000 years to allow decay of the fission products. This requirement was later included as part of the Part 60 rule proposed in July 1981 (Ref. 11). It is apparent, then, that wastes which still contain appreciable activity after several hundred years (e.g., 500 years) would appear to more closely resemble high-level waste than what is usually considered to be low-level waste.

Finally, limitations on the effectiveness of barriers to a potential inadvertent intruder was discussed at the regional workshops on the Part 61 regulation. At these workshops, there appeared to be general agreement that a time period of 500 years seemed appropriate for most easy-to-implement intruder barriers.

Based upon the analyses and discussion of the previous subsections, the following conclusions can be reached:

1. The potential for inadvertent human intrusion into a closed disposal facility at some point after closure of the disposal facility is likely. Extensive intrusion activities such as major housing or apartment construction are unlikely. The potential exposures from inadvertent intrusion are relatively high for the first few hundred years (i.e., 3-6 rem/year) but, provided a few waste streams are removed, then drop to a low level (few mrem/year).

2. Some waste streams present relatively little hazard to an inadvertent intruder. Some present an initial high potential hazard. If inadvertent intruders can be protected against contacting these latter waste streams for a few hundred years, then such waste streams present much reduced potential hazards. Some waste streams may not be acceptable for near-surface disposal.

3. The extent and consequences of potential inadvertent intrusion are related to waste form, design, and operating practices. For example, improved waste form and packaging can reduce potential exposures through inhalation and food consumption pathways. Volume reduction may increase exposures from direct gamma radiation. If the waste is in a structually stable form and segregated from other wastes, then as long as the structural stability is retained, the possibility of extensive inadvertent intrusion activities is not considered credible.

4. Natural and engineered barriers can be used to reduce potential intruder exposures. However, there is a limit (e.g., 500 years) as to how long such barriers can be expected to last.

5. Institutional controls can be effective in reducing the potential for inadvertent intrusion and in reducing potential intruder exposures.

Two aspects must be analyzed in further detail and specific limits developed to determine the disposal requirements of different LLW streams based on protection of an inadvertent intruder--that is, to determine which streams may be acceptable for near-surface disposal, which streams may require barriers to an intruder, and which streams may be altogether unacceptable for near-surface disposal. The aspects that must be developed include:

1. An exposure guideline to define an acceptable level of safety regarding protection of an inadvertent intruder which can be used to stipulate when controls against potential intrusion should be implemented;

2. A maximum time during which active institutional controls can be relied on to prevent inadvertent intrusion; and

These two aspects and others are addressed in the remaining two sections regarding development of an intruder performance objective and technical requirements.

4.5 DEVELOPMENT OF INTRUDER PERFORMANCE OBJECTIVE

4.5.1 Analysis of Intruder Dose Limitation Guidelines

Prior to determining a dose guideline for protection of a potential inadvertent intruder, it is useful to briefly review a number of radiation exposure guidelines which have been recommended by various bodies or adopted by regulatory agencies. The reader is referred to Appendix N, which presents a brief review of radiation exposure guidelines as have been developed by the following groups:

- ICRP
- NCRP
- EPA
- NRC

From the discussion in Appendix N, it appears that a wide range of exposure criteria have been recommended by national and international committees or adopted as regulations by NRC and EPA. These criteria range from a few millirem to a few dozen millirem to several rems. In general, the lower exposure limitation criteria (a few to a few dozen mrem) are used as standards assuming continuous exposure to radionuclides by populations. Higher dose limits (hundreds of mrem) are generally used as standards assuming exposures to a few individuals in unrestricted areas. Still higher exposure limits (a few rems) are considered appropriate for limits to radiation workers. Finally, a few dozen rems is an exposure guideline which has been recommended for once-in-a-lifetime exposures for an emergency situation.

Three alternative dose guidelines may be further examined, which serve to bound a low, moderate, and high dose guideline. In considering this range, one important concept that should be remembered is that the exposures potentially experienced by an intruder would not be routine. Such exposures would be accidental and would furthermore not be expected to last for long time periods--particularly if the waste so encountered has been placed into a stable form. The three guidelines so examined are in the following ranges:

1. 25 mrem to the whole body;
2. 500 mrem to the whole body; and
3. 5 rem to the whole body.

Twenty-five mrem/year is derived from 40 CFR Part 190 and is the EPA standard applied to the whole body and organ (except thyroid) exposures involving releases of material to the general environment through normal fuel cycle facility operations. This standard has been adopted by NRC as part of NRC regulations in 10 CFR Part 20. Since this is an accepted standard, it would appear to provide an adequate level of protection. It does not appear appropriate, however, to apply this standard to exposures to potential inadvertent intruders. This standard applies to routine releases to the general environment involving exposure of several individuals of larger population groups. The standard would not seem to apply to the type of localized "accidental" exposure to a few individuals who might intrude into the waste. Inadvertent intrusion is accidental and of a short-term temporary nature and is not expected to involve longer-term routine operational releases. A limit higher than 25 mrem/year would therefore appear to be appropriate, particularly since intrusion involves only a few individuals.

Five rem/year to the whole body is derived from the occupational external whole body radiation exposure guideline recommended by NCRP and set out by NRC in 10 CFR Part 20. Since this is also a generally accepted standard, it would also seem to provide an adequate level of protection. Such an exposure to an intruder would not be life threatening, and would involve exposures no higher than allowable today for some individuals. The standard, however, is applied to radiation workers who understand and accept the low risk of exposure involved in their job and livelihood. The inadvertent intruder is not a radiation worker and he may have no knowledge of the risk of exposure even after he digs into the waste.

Dose limitations in the range of 500 millirem/year to the whole body have been recommended by various groups for a number of years as adequate for protection of individuals. In making this recommendation, these groups maintain that protecting individuals to this level will almost certainly protect populations. For example, ICRP states that protection of an individual to a level of 500 mrem/year will almost certainly guarantee potential population exposures to less than one-tenth of the maximum individual dose. The current recommendations of the National Council on Radiation Protection and Measurements (NCRP) for radiation protection guidelines are 500 mrem/year (whole body) to the maximum exposed individual and 170 millirem/year as an average yearly population dose. These recommendations were adopted by the Federal Radiation Council (FRC) and recommended in 1960 as federal guidance. NRC limits in 10 CFR Part 20 for exposures to individuals in unrestricted areas are currently set at 500 mrem/year (whole body), based upon recommendations of the FRC and NCRP.

The International Commission on Radiation Protection (ICRP) has also recommended similar limits for a number of years. In more recent recommendations, however, ICRP has retained the recommended whole body dose limits of 500 mrem/year but dropped the 170 mrem/year population dose recommendation as not necessary. In so doing, ICRP states that protection of an individual to a level of 500 mrem/year would almost certainly guarantee potential population exposures to less than one-tenth of the maximum individual dose. ICRP also now recommends use of a weighting system to account for the fact that certain bodily organs and extremities are more radiosensitive than others. In the system, the dose to any individual organ or groups of organs would be controlled so that the sum of the doses to each individual organ times a given organ-weighting factor would not exceed 500 millirem for all organs. This weighting system, however, has not been adopted by NRC, although it may be in the future.

A dose guideline of 500 mrem/year to the whole body would therefore appear to be acceptable for protection of an inadvertent intruder. Such potential intrusion may never occur and if it should occur, would only be expected to involve local exposure of a few individuals. The use of a 500 mrem/year dose guideline has also been extensively discussed at the four regional workshops held by NRC on LLW disposal. Comments on this guideline were also received on the preliminary draft regulation 10 CFR 61 which was made available for public comment. The workshops and public comments are discussed in Appendix C. Broad acceptance of this guideline was generally expressed in these workshops and comments.

4.5.2 Analysis of Alternatives

Alternative dose limitations and institutional control periods for use in establishing performance objectives for protection of a potential inadvertent intruder may also be examined numerically. That is, depending upon different assumptions regarding dose criteria and institutional control periods, different calculated volumes of waste would require disposal by various methods. These volumes (and the resulting intruder exposures calculated) may then be examined and an estimate made of the cost-effectiveness of different alternatives.

Two factors complicate this analysis. One is that in determining performance objectives for inadvertent intrusion, one cannot examine alternative dose limitations independently of the institutional control period. For example, in order to assess the effects of alternative dose limitations, one must first set an institutional control period. Similarly, one cannot assess the effects of alternative institutional control periods without first setting a dose limitation criteria. The second factor is the number of variables which could be considered in the analysis. Some of these variables include the dose limitation criteria, the waste spectrum, the institutional control period, the region of the country, and the facility design. Several thousand permutations are possible. Even if one limits oneself to 3 alternative dose limitation criteria, 4 alternative waste spectra, 4 alternative institutional control periods, 1 region (the reference facility), and 2 facility designs, the number of possible permutations comes to 96. If one also considers the effect on the results of "waste form credit" and "no waste form credit" assumptions regarding the effect of waste form on dispersibility and root uptake, the number of possible permutations becomes 192. Clearly, some simplifying assumptions must be made to enable meaningful results.

For the analysis, therefore, NRC staff has considered 24 cases as shown in Table 4.20. In Cases 1-8, the dose limitation criteria (500 mrem whole body) and the waste spectrum (spectrum 1) are fixed, and the effects of four different institutional control periods (50, 100, 150, and 300 years) are considered. In Cases 9 through 14, the dose limitation criteria is still fixed at 500 mrem (whole body) and the effects of different waste spectra are considered. Cases 15 through 19 consider the effects of a dose limitation in the range of 25 mrem (whole body), while Cases 20 through 24 consider the effects of a dose limitation criteria in the range of 5 rem (whole body).

In each of the 24 cases, the waste streams are assumed to be randomly disposed into the reference disposal facility. Three potential forms of disposal to reduce intruder impacts are considered--i.e., disposal near the surface, layering, and not acceptable for near-surface disposal. In the 24 cases, no credit is assumed for the ability of waste form to reduce dispersibility and plant root uptake. The details of the calculational procedure are set out in Appendices G and H. Briefly, however, each waste stream is first tested for intruder impacts from disposal near the earth's surface, assuming the intruder scenarios discussed earlier occur (i.e., the intruder-construction scenario and the intruder-agriculture scenario). The calculated impacts are compared against the assumed dose limitation criteria immediately after the assumed end of the institutional control period. If the calculated impacts exceed the dose limitation, the waste stream is then assumed to be layered (disposed at the bottom of the trench), which considerably reduces the potential exposures received. However, the effectiveness of layering as an intruder barrier is assumed only to be effective for 500 years, after which time the potential impacts from intrusion are again compared against the assumed dose limitation criteria. As before, the intruder-construction and intruder-agriculture scenarios are conservatively assumed to occur. If the calculated impacts exceed the dose limitation criteria, the waste stream is assumed to be not acceptable for near-surface disposal.

The volumes of waste assumed to be suitable for disposal by each classification--i.e., regular disposal, layered disposal, or not acceptable--are shown for each case on Table 4.20. Also shown is the volume averaged intruder impacts calculated for the intruder-construction scenario and the intruder-agriculture scenario to each of two organs: whole body and bone. The impacts are calculated at the end of the institutional control period and are volume-weighted averages of exposures received from all waste streams acceptable for disposal--i.e., from regular and layered disposal. The doses calculated are an indication of the range of the actual likely exposures received from application of the indicated dose limitation criteria after the end of the indicated institutional control period. Exposures are also shown for a time period 500 years after license termination, at which time no credit is assumed for layering to reduce intruder exposures.

Finally, two different disposal facility design practices are considered in the analysis--i.e., whether or not compressible wastes are segregated from other waste streams during disposal. As discussed earlier, this can have a significant effect on the potential intruder impacts. If waste segregation is implemented, then the extensive intruder-construction scenario and intruder-agriculture scenario is assumed to be only applicable to the compressible wastes. For wastes

Table 4.20 Comparison of Cases to Determine Intrusion Performance Objective

Case Description and Impact Measures		Case a	b	c	1	2	3	4	5	6	7	8	9	10
Case Description:														
Dose limitation criteria (mrem)		NA	NA (No TRU)	NA (No TRU)	500	500	500	500	500	500	500	500	500	500
Waste spectrum		1	1	1	1	1	1	1	1	1	1	1	2	2
Institutional control period (yrs)		100	100	100	50	50	100	100	150	150	300	300	100	100
Segregation (yes/no)		No	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Intruder Impacts:														
Body (mrem)														
o ICP	C	1.50E+3	1.21E+3	1.16E+3	8.43E+1	8.69E+1	8.05E+1	3.09E+1	3.65E+1	2.12E+1	1.28E+1	1.22E+1	4.09E+1	3.26E+1
	A	1.77E+3	1.49E+3	1.41E+3	9.51E+1	7.35E+1	8.47E+1	2.50E+1	3.83E+1	2.00E+1	1.44E+1	1.37E+1	4.59E+1	2.15E+1
o 500	C	7.81E+1	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.53E+0	1.93E+0	1.93E+0
	A	4.34E+1	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	1.76E+0	2.21E+0	2.21E+0
Bone (mrem)														
o ICP	C	3.10E+3	1.21E+3	1.17E+3	8.89E+1	9.53E+1	8.78E+1	3.62E+1	4.31E+1	2.62E+1	1.96E+1	1.77E+1	4.57E+1	3.36E+1
	A	2.48E+3	1.56E+3	1.51E+3	1.10E+2	8.51E+1	9.08E+1	2.97E+1	4.12E+1	2.20E+1	1.64E+1	1.52E+1	5.50E+1	2.61E+1
o 500	C	1.18E+3	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	4.52E+0	6.25E+0	6.25E+0
	A	4.85E+2	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	3.46E+0	4.67E+0	4.67E+0
Volumes: (m^3)														
Regular		1.0E+6	9.80E+5	9.80E+5	6.88E+5	8.64E+5	8.81E+5	8.82E+5	9.08E+5	9.09E+5	9.77E+5	9.77E+5	4.76E+5	6.76E+5
Layered		-	-	-	2.92E+5	1.15E+5	9.91E+4	9.77E+4	7.14E+4	7.04E+4	2.66E+3	2.66E+3	2.02E+5	2.87E+3
Not accept.		-	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4	1.94E+4
Disposal Costs: ($)														
Design and Op.		1.85E+8	1.85E+8	1.90E+8	1.93E+5	1.95E+8	1.88E+8	1.94E+8	1.88E+8	1.94E+8	1.86E+8	1.92E+8	1.88E+8	1.88E+8
Postoperational		3.82E+7	3.82E+7	3.82E+7	3.09E+7	3.09E+7	3.82E+7	3.82E+7	4.29E+7	4.29E+7	4.88E+7	4.88E+7	3.82E+7	3.82E+7
Total NSD:		2.23E+8	2.23E+8	2.28E+8	2.24E+8	2.26E+8	2.26E+8	2.32E+8	2.31E+8	2.37E+8	2.35E+8	2.41E+8	2.26E+8	2.26E+8
Mined Cavity ($)		-	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6	9.93E+6
Repository ($)		-	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8	1.01E+8

Table 4.20 (continued)

Case Description and Impact Measures	Case 11	12	13	14	15	16	17	18	19	20	21	22	23	24
Case Description:														
Dose limitation criteria (mrem)	500	500	500	500	25	25	25	25	25	5000	5000	5000	5000	5000
Waste spectrum	2	2	3	4	1	1	2	3	4	1	1	2	3	4
Institutional control period (yrs)	300	300	100	100	100	100	100	100	100	100	100	100	100	100
Segregation (yes/no)	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Intruder Impacts:														
Body (mrem)														
o ICP C	1.50E+1	3.94E+1	2.83E+1	3.84E+1	1.37E+0	1.90E+0	2.47E+0	3.56E+0	2.12E+0	1.15E+2	6.71E+1	3.43E+1	3.08E+1	6.41E+1
A	1.71E+1	3.43E-1	2.11E+0	4.47E+1	2.74E+0	1.74E+0	5.02E-1	6.23E-1	1.30E+0	1.22E+2	6.34E+1	2.14E+1	2.10E+0	4.37E+0
o 500 C	1.93E+0	1.93E+0	3.08E+0	6.41E+0	2.50E-1	2.50E-1	1.58E+0	2.60E+0	6.90E-1	1.53E+0	1.53E+0	1.93E+0	3.08E+0	6.41E+0
A	2.21E+0	2.21E+0	3.48E+0	7.22E+0	3.08E-1	3.08E-1	1.81E+0	2.88E+0	8.06E-1	1.76E+0	1.76E+0	2.21E+0	3.48E+0	7.22E+0
Bone (mrem)														
o ICP C	2.26E+1	6.33E-1	2.90E+1	3.92E+1	1.85E+0	2.11E+0	2.65E+0	3.71E+0	2.29E+0	1.24E+2	7.41E+1	3.48E+1	3.10E+1	6.45E+1
A	2.00E+1	8.86E-1	4.53E+0	9.59E+0	6.71E+0	4.28E+0	1.99E+0	2.48E+0	5.18E+0	1.30E+2	7.07E+1	2.60E+1	4.50E+0	9.37E+0
o 500 C	6.25E+0	6.25E+0	9.04E+0	1.88E+1	1.66E+0	1.66E+0	5.59E+0	8.03E+0	3.19E+0	4.52E+0	4.52E+0	6.25E+0	9.04E+0	1.88E+1
A	4.67E+0	4.67E+0	6.60E+0	1.37E+1	1.23E+0	1.23E+0	3.96E+0	5.35E+0	2.30E+0	3.46E+0	3.46E+0	4.67E+0	6.60E+0	1.37E+1
Volumes: (m^3)														
Regular	6.75E+5	6.78E+5	4.89E+5	2.31E+5	3.32E+5	5.18E+5	3.97E+5	3.16E+5	1.52E+5	9.09E+5	9.10E+5	6.78E+5	4.92E+5	2.36E+5
Layered	3.67E+3	-	2.87E+3	5.21E+3	5.70E+5	3.84E+5	2.75E+5	1.65E+5	3.39E+4	7.06E+4	6.96E+4	-	-	-
Not accept.	1.94E+4	1.94E+4	1.13E+3	1.13E+3	9.70E+4	9.70E+4	2.62E+4	1.22E+4	5.19E+4	1.94E+4	1.94E+4	1.94E+4	1.13E+3	1.13E+3
Disposal Costs: ($)														
Design and Op.	1.84E+8	1.88E+8	1.85E+8	1.82E+8	1.99E+8	2.00E+8	1.94E+8	1.89E+8	1.82E+8	1.88E+8	1.94E+8	1.88E+8	1.85E+6	1.81E+8
Long-term Care	4.88E+7	4.88E+7	3.82E+7	3.82E+7	3.82E+7	3.82E+7	3.82E+7	3.83E+7	3.82E+7	3.82E+7	3.82E+7	3.82E+7	3.82E+7	3.82E+7
Total NSD:	2.33E+8	2.37E+8	2.23E+8	2.20E+8	2.37E+8	2.38E+8	2.32E+8	2.27E+8	2.20E+8	2.26E+8	2.32E+8	2.26E+8	2.23E+8	2.19E+8
Mined Cavity ($)	9.93E+6	9.93E+6	5.79E+5	5.79E+5	4.97E+7	4.97E+7	1.34E+7	6.25E+6	2.66E+7	9.93E+6	9.93E+6	9.93E+6	5.79E+5	5.79E+5
Repository ($)	1.01E+8	1.01E+8	5.88E+6	5.88E+6	5.04E+8	5.04E+8	1.36E+8	6.34E+7	2.70E+8	1.01E+8	1.01E+8	1.01E+8	5.88E+6	5.88E+6

which are segregated and stable, the intruder-agriculture scenario is assumed not to occur and the intruder-construction scenario is considerably reduced in its impact. (This is also termed the intruder-discovery scenario.) The full extensive intruder scenarios are conservatively applied for all waste streams at 500 years whether or not the waste stream is segregated or the waste is in a stable form. Impacts at the end of the institutional control period and at 500 years are again volume-averaged over all (stable and unstable) waste streams accepted for disposal.

4.5.3 Results of Analysis

The results of the 24 case studies are shown in Table 4.20. Also shown in this table is an additional case which illustrates costs and impacts of no action (case a), as well as two cases (cases b and c) for which the L-DECONRS and N-SOURCES waste streams are removed but no other action is taken to protect a potential inadvertent intruder (no layering is performed for any waste streams).

Across the top of the table are listed the descriptions of the cases. The variables considered include the dose limitation criteria, the waste spectrum, the institutional control period, and whether or not segregation is implemented at the disposal facility. Next, radiological impacts in mrem to whole body and bone are listed for the intruder-construction and intruder-agriculture scenario for two time periods after license termination: at the end of the assumed institutional control period and at 500 years. Next, the volumes (in m^3) are shown for waste disposed as regular waste, disposed as layered waste, and not acceptable for disposal.

Costs are listed toward the bottom of the table. Shown are design and operation costs, postoperational costs (closure and long-term care costs), and total (design and operation plus postoperational care) near-surface disposal costs. Design and operation costs are calculated as a total sum over 20 years of facility operation and are a function of facility design (whether or not segregation is implemented), the dose limitation criteria chosen, and the waste spectra. The less the volume of waste delivered to the disposal facility, the lower the total design and operation costs. For this analysis, postoperational costs were calculated by assuming a high level of long-term care effort for all cases. Differences in the long-term care costs for the cases are calculated solely as a function of the assumed length of the active institutional control period.

Costs for disposal of waste streams found to be not acceptable for near-surface disposal are also illustrated as two examples. In the first example, the waste streams unacceptable for near-surface disposal are assumed to be disposed into a mined cavity which is licensed to a commercial operator. Costs are calculated based upon an estimate of $512 per cubic meter of waste, which is the lower end of the range for mined cavity disposal given in Appendix F. This level of costs is based upon an assumption that an existing mine may be used and does not include any storage costs prior to shipment of the waste to the mine. In addition, the costs do not include cost for closure and long-term care of the mined cavity. In the second example, costs are estimated based upon an assumption that the Department of Energy accepts the waste for disposal into a federal repository. Costs are calcualted based upon an estimate of $5200/m^3 of waste, which includes costs for retrievable storage, retrieval, processing, transportation, and disposal into a geologic repository.

These costs for the two examples are given in 1980 dollars and should be considered only illustrative approximations. There are currently no mined cavities licensed by either NRC or an Agreement State, and wastes would have to be stored until such time (if and when) such a facility is licensed. No analysis is performed in this EIS to determine if waste unacceptable for near-surface disposal would be acceptable in a commercially operated mined cavity. Many such wastes (particularly transuranic waste streams) unacceptable for near-surface disposal would probably end up as candidates for a federal repository. Additional costs would be involved for storage until either a disposal facility is available to accept the waste for disposal or DOE is in a position to accept the waste for retrievable storage.

Comparing Cases 1 through 8, several trends are observed:

1. The longer the assumed institutional control period, the greater the volume of waste that can be disposed by less expensive methods. For example, the ratio of the volume of waste that can be disposed by regular means vs. the volume of waste that must be disposed through layering is as follows: Case 2: 7.51; Case 4: 9.03; Case 6: 12.91; Case 8: 367.29. As long as only a relatively small volume of waste requires layering (e.g., as in Cases 4 through 8), then layering can be accomplished with little expense, with little or no disruption of existing practices, and with no decrease in disposal efficiency (no increase in land use). However, if large volumes of waste require layering (e.g., as in Case 1), then this could cause increased expense, some disruption of existing practices, and a decrease in disposal efficiency.

2. The longer the assumed institutional control period, the lower the potential exposures at the time that intrusion is assumed to occur (which is immediately after the end of the institutional control period). On the other hand, the longer the institutional control period, the greater the long-term care costs.

3. The practice of waste segregation generally slightly increases the quantity of wastes which may be disposed by less expensive means. For example, compare the volumes of waste in the "regular" class and the "layered" class for Cases 1 vs. 2; 3 vs. 4; and 5 vs. 6. This effect is of most significance for Cases 1 and 2.

4. The practice of waste segregation generally reduces potential intruder exposures.

5. The volume-weighted impacts calculated at the institutional control period are invariably significantly less than the assumed dose

limitation criteria. Of course, the longer the institutional control period, the lower the calculated impacts. Since varying the institutional control period does not vary the volume of waste calculated to be unacceptable for near-surface disposal (the N-SOURCES and L-DECONRS stream are calculated to be unacceptable in all 8 cases), the intruder impacts at 500 years do not vary from one case to the next. These impacts are in the range of about 1.5 to 4.5 mrem.

From the analysis in Cases 1 through 8, there does not appear to be any compelling analytical reason to choose one institutional control period over another. It appears that the assumption of whether or not waste segregation is carried out affects the volumes of waste disposed by either regular or layered means as much as the institutional control period chosen. In any case, provided waste segregation is implemented, there is no difference in total waste volumes disposed between an institutional control period of 50 years and 300 years.

Of the institutional control periods considered, 50 years would likely cause the most change to present practices, the most added design and operation expense, and the most likelihood of a potential decrease in disposal efficiency. In addition, it is very unlikely that the extensive intruder impacts considered in this EIS could occur at a time period only 50 years following license termination. Finally, implementation of a 50-year institutional control period may serve to inhibit volume reduction of wastes. In general, volume reduction is desirable as it can lower disposal costs to a waste generator, improve disposal efficiency (less land use), and increase the stability of the waste (lowering potential ground-water impacts and potential long-term care costs).

This leaves a choice in the range of 100 to 300 years. Since general support for 100 years was received at the regional workshops and the calculated difference in design and operations cost to a waste generator between 100 years and 300 years is low, the more conservative time period was selected.

Cases 9 through 14 illustrate the effects of other waste spectra, assuming a continuation of the previously assumed dose limitation criteria of 500 mrem to the whole body. Waste spectra 2 through 4 consider different degrees of volume reduction, and so the volumes classified are different from Cases 1 through 8. Of interest is a comparison of calculated intruder exposures for Cases 10, 13, and 14 with each other and with Case 4. In these four cases, the dose limit and the institutional control period are the same but different waste spectra are considered. The calculated exposures are similar at the end of the assumed institutional control period (100 years) for Cases 4, 10, and 13. Even for the extreme case of volume reduction assumed for waste spectrum 4 (Case 14), the calculated impacts are only a few mrem higher. After 500 years, intruder exposures are only slightly higher for all cases (except Case 14) than the exposures calculated for Cases 1-8. For Case 14, exposures are still less than 20 mrem for the intruder-construction scenario and less than 15 mrem for the intruder-agriculture scenario.

In addition, compared to Cases 1 through 8, no additional volumes of waste are classed as unacceptable for near-surface disposal. The same two streams as before--the N-SOURCES and L-DECONRS streams--are involved. As a minor perturbation, for Cases 13 and 14, the L-DECONRS stream is assumed to be calcined, resulting in significant volume reduction (to 1.13 E+3 m^3). The N-SOURCES waste stream (51.5 m^3), for which no volume reduction is assumed for any of the 4 spectra follows the familiar pattern of Cases 1 through 8.

What this analysis appears to indicate is that except for a few waste streams which are problematical in any case, use of an institutional control period of 100 years and dose limitation criteria of 500 mrem/yr (whole body) would not be expected to inhibit use of volume reduction as a waste processing technique.

Another interesting effect is observed by comparing Cases 7 and 8 with Cases 11 and 12. If waste segregation is not implemented, then the intruder impacts for waste spectrum 1 at 300 years is less than those for waste spectrum 2. However, if waste segregation is implemented, the opposite effect is seen.

The effects of using different dose limitation criteria are set out in Cases 15 through 24. In Cases 15 through 19, the dose limitation criteria is assumed to be in the range of 25 millirem whole body (75 millirem thyroid). In Cases 20 through 24, the dose limitation criteria is assumed to be 10 times that for Cases 1 through 14, or 5,000 mrem (5 rem) whole body. For all cases, the institutional control period is assumed to be 100 years.

As can be seen in Cases 15 through 19, use of an intruder dose limitation criteria in the range of 25 mrem (whole body) would tend to result in larger costs to waste generators. Due to reduced volumes of waste accepted for near-surface disposal, similar or somewhat reduced design and operation costs are calculated (e.g., compare Cases 15 and 16 with Cases 3 and 4; Case 17 with Case 10; or Case 18 with Case 13). However, mined cavity and repository costs are higher. For most of the waste spectra, approximately the same volume of waste must be layered as that which can be disposed unlayered. In addition, larger volumes of wastes would not be acceptable for near-surface disposal. For example, in Case 16, nearly 100,000 m^3 of waste would be classified as not acceptable. Compared to an intruder dose limitation criteria in the range of 500 mrem (whole body), use of the lower dose limitation criteria would result in higher costs, more changes to existing practices, and less efficient land use. There is no disposal facility yet constructed, such as a geologic repository, offering greater isolation than a near-surface disposal facility. This means that such wastes would have to be stored prior to disposal--perhaps for extended time periods.

In addition, although use of the 25 mrem dose limitation criteria results in reduced potential exposures at 100 years (by a factor of 10 for most cases), only a negligible difference in intruder exposures is seen at 500 years. This means that use of the 25 mrem (whole body) dose criteria will provide little additional reduction in long-term potential intruder exposures.

The effect of implementing the highest alternative dose limitation criteria (5 rem whole body) in Cases 20 through 24 is seen to be somewhat similar to the effects of a dose limitation criteria in the range of 500 mrem/yr. Similar to Cases 1 through 14, the L-DECONRS and N-SOURCES waste forms are always classed as being unacceptable.

Another interesting aspect is the volume-weighted intruder impacts. As before, the impacts calculated are invariably considerably less than the dose limitation criteria. In addition, the impacts calculated for the higher (5 rem) criteria are similar to those previously calculated for the 500 mrem criteria. This implies that one could possibly use two dose limitation criteria--a lower one (e.g., 500 mrem) for longer-lived higher hazard isotopes such as transuranics and a higher one (e.g., 5 rem) for shorter half-lived fission products such as Cs-137. Use of a higher dose limitation criteria for shorter-lived isotopes could cause an initial higher hazard. Use of such a criteria would have little effect on the long-term hazard, however. For example, if it is assumed that a raise in the Cs-137 limit by tenfold from 500 mrem to 5 rem causes a tenfold increase in potential intruder hazard (unlikely as the above analysis indicates) and the higher activity waste is stabilized and segregated (e.g., waste spectra 2, Cases 10 and 22), then the potential exposures would still be less than 500 mrem/yr. These higher potential exposures would only last for a short time period, and would fall by a factor of 10 in a space of only 100 years.

As shown, the impacts at 500 years are similar to those calculated for Cases 1-8.

It may also be useful to examine use of a "hot waste facility" for possible disposal of waste streams found in the 24 cases to be unacceptable for disposal.

For the purposes of this analysis, the hot waste facility is assumed to be a cement-walled trench into which wastes are stacked and then grouted in place. A one-meter thick concrete cap is then poured over the waste and a few meters of earth are then emplaced over the facility. Thus, the waste is enclosed in a large monolithic block of concrete. The facility is assumed to be effective for 1000 years, after which the potential intrusion impacts are calculated and compared against the assumed dose limitation criteria. The intruder-construction and intruder-agriculture scenarios are assumed to occur, but are assumed to be reduced by a factor of 10 due to the presence of the concrete fill. If the calculated exposures still exceed the assumed dose limitation criteria, the waste is assumed to be unacceptable for near-surface disposal.

It is recognized that there are uncertainties regarding use of the "hot waste facility," and its effectiveness. However, it is included to enable an estimate of the effectiveness of extensive near-surface disposal techniques to reduce potential intruder exposures. Use of a hot waste facility is estimated to be much more expensive than either regular or layered disposal. If a hot waste facility were not used at the disposal facility, then the waste streams assumed to be suitable for disposal into a hot waste facility would be considered unacceptable for near-surface disposal.

Potential use of the hot waste facility for disposal of probable material waste was tested for all 24 cases and in no case were the N-SOURCES and L-DECONRS streams found to be acceptable for hot waste facility disposal. This would be expected considering that these two streams are assumed to contain relatively large quantities of transuranic isotopes and no credit is being taken in the analysis for the long-term ability of improved waste forms to reduce dispersion of the waste into respirable particles. However, in 4 cases, other waste streams previously found unacceptable for near-surface disposal were found to be suitable for hot waste facility disposal. These were Cases 15, 16, 18, and 19 and the costs and impacts of these 4 cases are presented in Table 4.21. All 4 cases involve use of the 25 mrem (whole body) dose limitation criteria.

As shown in Table 4.21, about half of the waste which was previously determined to be unacceptable for near-surface disposal in the 4 cases is found to be acceptable for hot waste facility disposal. However, design and operation costs are raised above the previous cases, and the total costs for mined cavity or repository disposal are still higher than equivalent cases using the other two alternative dose limitation criteria.

4.5.4 Selection of Preferred Alternative

Based upon the preceding analyses, a performance objective for potential inadvertent intrusion may be established. Establishing the performance objective requires establishing a dose limitation criteria for intrusion as well as a time limitation for active institutional controls.

The preferred dose limitation criteria objective selected by NRC is the same as the maximum unrestricted area exposures as set out in 10 CFR Part 20, or 500 mrem/yr to the whole body. A dose limit in the range of 25 mrem/year was judged to result in considerably more costs, more change in existing practices, and greater reduction in disposal efficiency than the other two alternatives. This is especially important considering the hypothetical nature of the intrusion event. The 5 rem alternative was seen to involve approximately the same costs and impacts as the 500 mrem alternative. The higher dose limit, however, could potentially allow disposal of larger quantities of long-lived isotopes, which could result in moderately higher intruder hazards which could extend for long time periods. Therefore, 500 mrem/yr was selected as a general dose limitation guideline. This limitation agrees with the concerns of the four regional workshops. In this regard, it was also observed in the above analysis that a higher limitation could actually be safely used for shorter-lived isotopes such as Cs-137. Use of such a limit would have no effect on the longer-term hazard to an intruder.

The second part of the inadvertent intrusion performance objective is how long should credit be given to active institutional controls to prevent such intrusion. A time period that is too short could result in very high disposal costs for much of the LLW. A period that is very long, on the other hand, may place an undue burden on future generations. NRC analyzed alternative institutional control periods of 50, 100, 150, and 300 years to see if there was any technical preference for selecting one time period over another. From the analysis, there did not appear to be any overly compelling numerical reason to adopt a particular institutional control period. NRC believes, however, that institutional controls will last at least 50 years. 300 years appeared to be too long of a time period and did not offer any compelling numerical advantage over 150 years. The preferred alternative was, therefore, in the range of 100 to 150 years. NRC selected 100 years as the preferred institutional control period. This period of time agrees with previous estimates on the effective

Table 4.21 Comparison of Cases Incorporating a Hot Waste Facility

Case Description and Impact Measures			Case 15	Case 16	Case 18	Case 19
Case Description:						
Dose limitation criteria (mrem)			25	25	25	25
Waste spectrum			1	1	3	4
Institutional control period (yrs)			100	100	100	100
Segregation (yes/no)			No	Yes	Yes	Yes
Intruder Impacts:						
Body (mrem)						
o	100	C	1.23E+0	1.75E+0	3.53E+0	2.11E+0
		A	2.38E+0	1.59E+0	6.18E-1	1.28E+0
o	500	C	2.50E-1	2.50E-1	2.60E+0	6.90E-1
		A	3.08E-1	3.08E-1	2.88E+0	8.06E-1
Bone (mrem)						
o	100	C	1.80E+0	2.03E+0	3.68E+0	2.31E+0
		A	5.84E+0	3.90E+0	2.46E+0	5.08E+0
o	500	C	1.66E+0	1.66E+0	8.03E+0	3.19E+0
		A	1.23E+0	1.23E+0	5.35E+0	2.30E+0
Volumes: (m^3)						
Regular			3.32E+5	5.18E+5	3.16E+5	1.52E+5
Layered			5.70E+5	3.84E+5	1.65E+5	3.39E+4
HWF			4.97E+4	4.97E+4	2.93E+3	2.93E+3
Not acceptable			4.73E+4	4.73E+4	9.26E+3	4.89E+4
Disposal Costs: ($)						
Design and op.			2.15E+8	2.16E+8	1.92E+8	1.85E+8
Postoperational			3.82E+7	3.82E+7	3.82E+7	3.82E+7
Total NSD:						
Mined Cavity: ($)			2.42E+7	2.42E+7	4.74E+6	2.50E+7
Repository: ($)			2.46E+8	2.46E+8	4.82E+7	2.54E+8

length of active institutional controls made by EPA and also is consistent with the consensus of the regional workshops. NRC identified no overriding social or political rationale for selection of one time period over another. Based on the comments received on the preliminary draft of Part 61 and the workshops held, the general consensus was that 100 years was about the right time period upon which reliance should be placed on active institutional controls.

4.6 DEVELOPMENT OF TECHNICAL CRITERIA

Based on the preceding analysis, NRC selected minimum requirements that should be considered and applied in all cases to help ensure that the performance objective will be met. The results indicate that with modest increases in cost (relating to improving the form and properties of waste shipped for disposal, improvements in the design and methods of disposal for certain high activity wastes, and application of institutional controls for a reasonable period of time), the potential impacts to an inadvertent intruder can be greatly reduced.

The following subsections present the technical requirements selected, based on the preceding analysis, to assure protection of the inadvertent intruder. The requirements deal with each of the four basic components of any disposal facility: institutional controls, site characteristics, design and operations, and waste form and packaging. The requirements are set out in general terms with the intention of setting out the overall intent of the requirements rather than providing the precise regulatory wording. Some of the requirements are new and are derived from the above analysis. Others only involve a codification of existing practices currently being applied at the existing disposal facilities.

4.6.1 Institutional Control Requirements

1. Requirement

   Disposal of radioactive waste received from other persons shall be permitted only on land owned by the federal government or by the state government in which the site is located.

Analysis

Present requirements in Section 20.302(b) of 10 CFR Part 20 require federal or state government ownership of land used for commercial disposal of radioactive waste. At 5 of the 6 existing commercial disposal sites, the land used for waste disposal was purchased by the disposal facility operator who then deeded the land to state ownership. The state then leased the land back to the disposal facility operator. At the commercial disposal facility located in the Hanford Reservation, however, the disposal site land is owned by the federal government. In this case, the land was leased by the federal government to the state of Washington, who then subleased the land to the disposal facility operator. NRC believes that the existing requirement for government land ownership should be continued since there is a higher degree of assurance that the state or federal government will continue to exist for longer periods of time than a private organization. The need for control of near-surface disposal facilities will last for one hundred years. Adapting this provision in 10 CFR 61 for state or federal ownership of land used for disposal of waste received from other persons would involve no change from existing regulations and no increase in cost over what is already being done today. The costs for government land ownership have been included in the base case analyses of costs and impacts.

2. Requirement

The land owner shall carry out an active institutional control program to physically control access to the site following transfer of control from the site operator. Active institutional controls shall not be relied upon for more than 100 years.

Analysis

Active institutional control is an extension of the existing requirement for government land ownership and involves the physical controls and surveillance of a site carried out by the state or federal government land owner to preclude inadvertent intrusion and carry out other control and surveillance activities. As a part of these control and surveillance activities, the site owner would carry out an environmental monitoring program to check on the continued performance of the site, administer funds to cover the costs of these "active institutional control" activities, carry out minor maintenance activities that may be required (e.g., upkeep of a security fence), and carry out other necessary responsibilities. An active institutional control program is a codification of existing practice at the existing sites including the need to collect and administer funds to cover the costs of this control program.

Given such an active control program, a basic question remained, however, regarding how long reliance can or should be placed on such active institutional controls. NRC recognizes that such active controls could very well last for several hundreds of years based on the actions of those responsible for such a program in the future. For purposes of Part 61, however, NRC will assume such controls can only be relied upon for 100 years. The costs for 100 years of active institutional control have been included in the base case analysis of costs and impacts.

3. Requirement

Disposal cells shall be surveyed, mapped, and the location and hazard of the disposal facility recorded with a number of local, state, and federal agencies.

Analysis

By definition, an inadvertent intruder is one who unknowingly contacts the radioactive waste without knowing that it is there. Therefore, it is important to consider passive methods by which the presence of hazardous materials may be communicated to future generations, thus minimizing or potentially even eliminating the possibility of inadvertent intrusion. First, transferring records of the disposal facility location to a diversity of locations throughout all levels of government will help to ensure that an awareness of the potentially hazardous condition at the site will be known to future generations. Diverse locations could include local libraries, local zoning boards, state land development offices, local and statewide executive offices, and federal archives. The cost for this is low. Depending on site-specific conditions, the government could put the land to controlled productive use during the active institutional control program where the disposed waste would not be disturbed. The potential hazard of the disposal facility could also be recorded upon the deed or title to the land.

It is also important to maintain an accurate record of the locations at a disposal facility which are actually used for waste disposal. The locations of disposal cells can be readily surveyed, mapped, and referenced to a benchmark such as a USGS benchmark. This practice has a number of advantages:

- Surveys help to perpetuate a record of the disposal facility.
- Surveys help to provide quality assurance checks that disposal cells used for waste disposal are constructed according to approved specifications.
- Care in recording the locations of disposed waste serve to help identify disposal cells in case remedial action is required in the future.

All of the disposal facilities presently operating now require that locations of disposal trenches be surveyed and referenced to a benchmark. The cost for such surveys has been included in the costs for the reference facility.

4.6.2 Site Characteristics

The following site suitability requirements reflect existing practice to consider future population growth, land use development, and potential natural resources at the site. Since they reflect existing practice the cost and impacts are considered through the base case analysis, and no cost benefit analysis has been performed.

Requirement

1. Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal site to meet the intruder performance objective.
2. Areas must be avoided having economically significant natural resources, which, if exploited, would result in failure to meet the intruder performance objective.

Analysis

In siting of near-surface disposal facilities, areas of high population density should be avoided to help reduce the potential of inadvertent intrusion after the end of institutional controls. Areas that are remote and less densely populated would generally be less likely to be immediately utilized, reducing the potential for inadvertent intrusion. In addition, the site should not have any extensive natural resources on the ground surface, in the hydrogeologic units used for disposal or at greater depth such as to encourage drilling or excavation within the site after institutional controls end. Sites having resources at much greater depths below the disposed waste would be acceptable provided the exploitation of such resources would not affect the performance of the facility (e.g., lead to increased ground-water contact with disposal waste or result in decreased ground water travel times).

4.6.3 Design and Operations

Requirement

1. Higher concentration waste presenting higher hazard potential to an inadvertent intruder must be disposed of at a minimum depth (to the top of the waste) of 5 meters below final grade (or the surface of the cover) or must be disposed of with natural or engineered barriers that are designed to protect against inadvertent intrusion for at least 500 years.

2. Compressible wastes shall be segregated from and disposed of separately from waste in a stable noncompressible form.

Analysis

Many alternatives may be applied to reduce the impacts of inadvertent intrusion. Many have either been applied in the past at existing disposal facilities or will require only minor modification to existing designs and operational practices. Those that NRC examined in the earlier analysis were:

- Use of thicker disposal cell covers
- Use of special waste disposal cells such as caissons, walled trenches, or other "engineered structures"
- Layered disposal
- Slit trench disposal
- Grouting
- Engineered intruder barrier

The results of the earlier analysis indicate that depth of burial (i.e., layering the waste) is the easiest to implement technically and costs the least. In this case, the more active waste would be preferentially placed toward the bottom of the trench. The potential intruder would tend to contact the lower-activity waste. Since many of high-activity waste streams which could be disposed in this manner would also be expected to contain high-surface gamma radiation levels, this technique would also help to reduce potential occupational exposures to disposal facility workers. The hot waste facility analyzed--a type of engineered structure--is probably the most difficult to implement technically and costs the most. Others fall in between except for significantly different methods of disposal (e.g., mined cavity disposal). To maintain flexibility in assuring protection of the inadvertent intruder by placing greater controls on the higher activity wastes, NRC selected no specific prescriptive requirement. Such flexibility will allow for regional differences in site characteristics, different facility designs, and individual preferences of disposal facility operators.

In determining which waste streams may not be acceptable for near-surface disposal, one of the questions is how long barriers to a potential intruder may be expected to last. Such barriers, of course, would be expected to last several hundred years but not forever. Some barriers may last longer than others. For example, the effectiveness of the "hot waste facility" discussed above to deter the actions of a potential intruder would be expected to last longer than a disposal method such as layering. From the analyses performed earlier in the EIS, it can be seen that due to radioactive decay, exposures to a potential intruder from almost all waste streams typically considered to be LLW have fallen to a few millirems after a few hundred years--e.g., 500 years. After 500 years, only a few waste streams are estimated to result in potential intruder exposures of a few hundred millirems. Very few (e.g., one or two streams) having small volumes are estimated to result in potential intruder exposures exceeding 500 mrem after 500 years.

The segregation of compressible wastes is discussed in the concluding section on waste form.

4.6.4 Waste Form and Packaging

Requirement

Higher activity waste shall have structural stability. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a disposal container or structure that provides stability after disposal. Void spaces within the waste and between the waste and its package shall be reduced to the extent practicable. The waste must maintain its physical dimensions and consistency under conditions of the compressive load, radiation, and biodegradation to be encountered in disposal.

Analysis

In general, placing the higher activity waste into a stable form and disposing of them together in a separate disposal unit segregated from compressible wastes reduces the impacts to a potential inadvertent intruder. The waste is less available for inhalation and uptake, and someone intruding into the site would be more likely to identify that they were not digging in soil if they found the remains of solid waste, and would take action to find out what it was before proceeding too far. Other details regarding analysis of this requirement, alternatives considered, and the preferred alternative selected by NRC are set out in Chapter 5.

REFERENCES

1. King, W.L., and J. J. Cohen, Interim Report to the Nuclear Regulatory Commission on Radioactive Waste Classification, UCID-17497, Lawrence Livermore Laboratory, April 18, 1977.

2. Adam, J. A., and V. L. Rogers, A Classification System for Radioactive Waste Disposal--What Waste Goes Where? NUREG-0456, FBDU-224-10, Ford, Bacon and Davis, Utah for NRC, June 1978.

3. Rogers, V. L., A Radioactive Waste Disposal Classification System, NUREG/CR-1005, Ford, Bacon and Davis, Utah for NRC, September 1979.

4. Leddicotte, et al., "Suggested Quantity and Concentration Limits to be Applied to Key Isotopes in Shallow Land Burial, "Management of Low-Level Radioactive Waste, Volume 2, Pergamon Press, 1979.

5. Healy, J. W., and J. C. Rodgers, Limits for The Department of Energy Transuranic Wastes, Los Alamos Scientific Laboratory, LA-UR-79-100, January 1979.

6. U.S. Nuclear Regulatory Commission, Final Environmental Statement Related to Primary Cooling System Chemical Decontamination at Dresden Nuclear Power Station, Unit No. 1, Docket No. 50-10, NUREG-0686, Office of Nuclear Reactor Regulation, October 1980.

7. Rogers, V., et al., Draft Report: Insights into Waste Disposal Options, FBDU-266-004, Ford, Bacon and Davis, Utah for Electric Power Research Institute, October 1979.

8. MacBeth, P., et al., Evaluation of Alternative Methods For the Disposal of Low-Level Radioactive Wastes, NUREG/CR-0680, July 1979.

9. U.S. Environmental Protection Agency, Proposed Criteria for Radioactive Wastes, Recommendations for Federal Radiation Guidance, Federal Register, 43 FR 53262, November 1978.

10. U.S. Nuclear Regulatory Commission, Advance Notice of Proposed Rulemaking on 10 CFR 60: Disposal of High-Level Radioactive Wastes in Geologic Repositories, Federal Register, 45 FR 31393, May 13, 1980.

11. U.S. Nuclear Regulatory Commission, Notice of Proposed Rulemaking on 10 CFR 60: Disposal of High-Level Radioactive Wastes in Geologic Repositories, Federal Register, 46 FR 35280, July 8, 1981.

Chapter 5

LONG-TERM ENVIRONMENTAL PROTECTION--PRESENTATION AND ANALYSIS OF ALTERNATIVES

5.1 INTRODUCTION

This chapter reviews a number of potential pathways for long-term release of radionuclides to the environment from disposed waste. These pathways include:

- o Ground-water migration;
- o Gaseous releases from decomposing waste;
- o Plant and animal intrusion; and
- o Wind and surface water erosion and transport.

Of these, NRC staff believes that the most significant pathway is ground-water migration. Gaseous releases do not have a large impact and can be reduced by assuring stable site conditions. Impacts from plant and animal intrusion are site-specific and can be reduced through engineering designs applied to reduce ground-water migration and potential intruder exposures. Erosion is a slow, long-term process which can be controlled through proper siting and good operational techniques.

Section 2 below analyzes ground-water migration presenting the impacts of the base case "no action" alternative and the incremental changes in those impacts due to application of a range of alternatives. In the analysis of alternatives, a number of cases are considered which represent a range of near-surface disposal technology options and waste forms. The results of these case study analyses illustrate a range of potential radiological impacts, disposal costs, and long-term maintenance requirements representative of application of current disposal technology. In these cases, the results from the preceding intruder analysis are incorporated into the case study analyses. This is done to account for any design and operational changes that may be required due to consideration of intruder protection.

Section 3 analyzes development of a performance objective for long-term releases to ground water leading to selection of a preferred performance objective. Section 4 reviews the other three potential environmental release pathways, presenting typical impacts based on existing published data in addition to ways to mitigate those impacts. Section 5 reviews technical requirements derived from the analyses, plus those involving codification of existing practice, that should be applied in the near-surface disposal of waste.

5.2 GROUND-WATER MIGRATION

To analyze potential ground-water migration impacts from near-surface radioactive waste disposal, NRC staff has adopted use of a model reference waste disposal facility located in a humid environment. To provide a reasonable yet conservative analysis, movement of radionuclides from the disposed waste and through ground water has been modeled based upon calculational procedures derived from Darcy's Law. (Additional information is contained in References 1 and 2.) As depicted in Figure 5.1, a disposal cell (or group of disposal cells) is assumed to be located within an unsaturated zone of thickness (Zo). Both the unsaturated zone and the underlying saturated zone (aquifer) are assumed to be stationary, homogeneous, and isotropic, and the fluid moving through these zones is assumed to be incompressible and of constant viscosity. The disposal cell is filled with a heterogeneous mixture of waste streams ranging from streams having very low activity to streams having relatively high activity. Each waste stream contains a particular suite of radioisotopes and, if contacted by water, leaches at a particular rate. Precipitating water striking a covered disposal cell may percolate into and flow through the cell and leach out a portion of the radionuclides contained in the waste.

The source term of each radioisotope in the disposed waste leaving the bottom of the disposal cell is given by (Jo) in Curies/year. The radioactive source moves down through the unsaturated zone with hydraulic velocity (w), and mixes with the water in the saturated zone. The water in the saturated zone, carrying the radiocontaminants with it, is then assumed to flow horizontally with hydraulic velocity (v). As illustrated in Figure 5.1, the contaminated ground water can be visualized as crossing a discharge surface at some arbitrary distance (x) downstream of the disposal cell(s), having a radionuclide activity equal to J (in Ci/yr).

The source term (Jo), and the factors that go into its determination, are discussed more extensively in Appendix G and Reference 1. It is a somewhat complicated function of site environmental conditions, disposal facility design and operating practices, waste characteristics (including waste leaching characteristics, radionuclide concentrations, chemical content, and structural stability), and the potential for intrusion by humans, plants, or animals. To provide a reasonable yet conservative analyses, the reference facility is assumed to experience a relatively high precipitation rate (1.17 m/yr) and a high natural percolation rate (PERC = 180 mm/yr). The percolation of water into disposal cells at the reference facility is a variable depending upon facility design and operating practices and waste form. For example, unstable waste forms would result in higher percolation of rainwater into disposal cells (due to subsidence of disposal cell covers), while improved thicker disposal cell covers and compaction techniques would reduce percolation. If the unstable waste streams were disposed mixed with the stable waste streams, then all of the wastes would experience higher percolation rates. However, if the unstable waste streams were disposed segregated from the unstable waste streams, then only the unstable waste streams would experience the higher percolation.

Percolation rates into disposal cells may also be increased through intrusion by inadvertent humans, deep-rooted plants, and burrowing animals. During the active institutional control period following license termination, the site owner would be expected to survey and maintain the disposal facility, to prevent inadvertent intrusion by humans, and to control and limit potential intrusion by deep-rooted plants and burrowing animals. However, following the active institutional control period, breakdowns in such surveillance and control

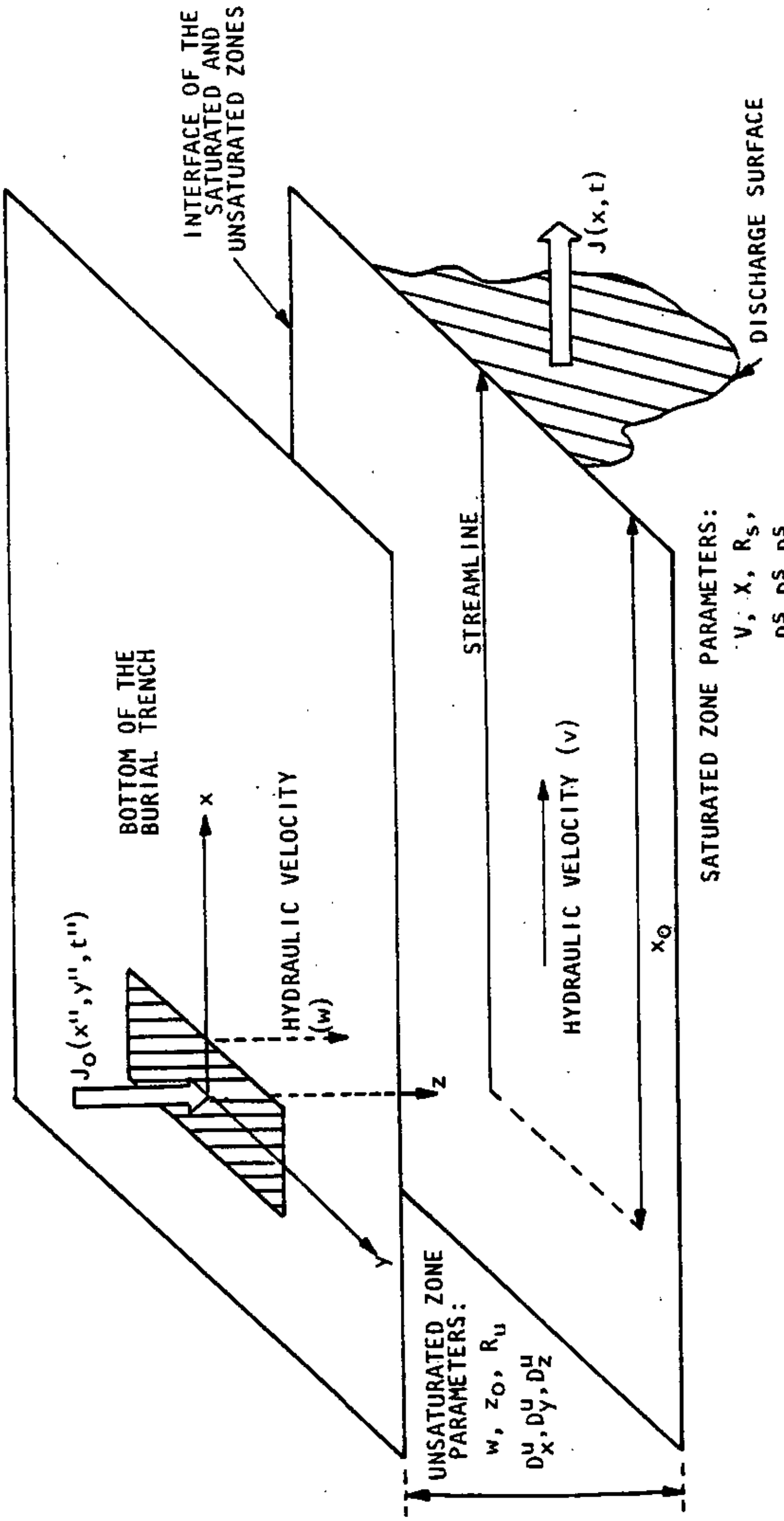


Figure 5.1 Geometry of Ground-Water Scenario

activities are postulated to occur. Therefore, for disposal facility designs which depend upon improved covers to reduce percolation (e.g., a walled trench, a compacted clay cap), a reduction in the effectiveness of these disposal covers is assumed at a time 100 years following license termination. The extent of this reduction in effectiveness is discussed in Appendix G. Briefly, however, 90% of the disposal area experiences percolation equal to twice the previously assumed value for that case. The remaining 10% experiences an even higher percolation, the specific value of which depends upon the case considered.

As another example, the leaching of radionuclides from the disposed waste depends upon the radionuclide content, whether the wastes are solidified, and the chemical content of the waste. Unsolidified waste streams are assumed to leach at a fraction corresponding to leach fractions measured under totally saturated conditions at the Maxey Flats, Kentucky and West Valley, New York disposal facilities. Solidified waste forms are assumed to leach at lower rates based upon an approximation derived from experimental data (Refs. 1, 3). However, increased leaching of solidified waste forms is assumed if chelating agents are present. If wastes containing chelating agents or organic chemicals are disposed in a segregated manner from other waste streams, then the higher leaching fractions are only applied to the segregated streams; otherwise, the higher leaching fraction is applied to all solidified streams.

After the radionuclides have left the disposal cell, the movement of radionuclides through ground water may be estimated by a number of calculation techniques-- many of which may be extremely complicated and require a great deal of site-specific information. Given the generic nature of this analysis, however, a simpler approximation in this EIS is used which allows rapid consideration and comparison of a number of alternatives. This approximation solves the Darcy's Law differential equations in terms of error functions as summarized in Appendix G. (Further information is contained in References 1 and 2.) Basically, however, the disposed waste is modeled as 10 distributed sources or sectors (which is more realistic than the assumption of a point source), as shown in Figure 5.2. Movement of radionuclides out of the sectors and to a biota access location is calculated principally as a function of the ground-water travel time from the sector to the access location, the Peclet number (basically the distance to the access location divided by the longitudinal dispersivity of the medium), and the retardation coefficients of the medium. The retardation coefficients assumed for the reference disposal facility are intended to correspond to soils having moderate permeability (See Table 5.2 in Section 5.2.1) and are radionuclide-specific. In this environmental impact statement, lower retardation coefficients are assumed for radionuclides contained in waste streams assumed to contain or be contacted by chelating agents or organic chemicals.

Radionuclide concentrations may be then determined as a function of time at four principal downstream biota access locations:

1. a well located on the disposal facility and potentially used by an inadvertent intruder following the end of the 100-year active institutional control period;

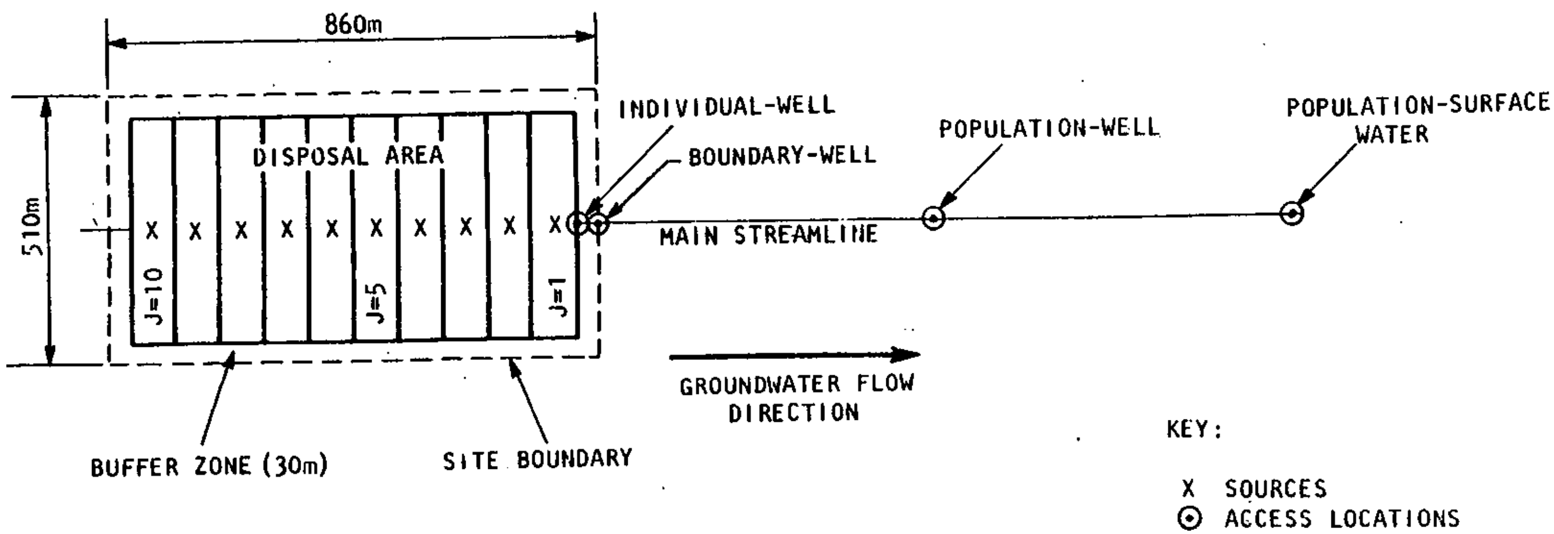


Figure 5.2 Geometric Relationships of Disposal Area and Ground-Water Access Locations

2. a well located at the site boundary which is assumed to be used by a few individuals;

3. a well assumed to be located approximately 500 meters down gradient from the disposal facility and used by a small population of about 100 persons; and

4. a small stream located about one kilometer down gradient from the disposal facility and assumed to be used by a small population of about 300 persons.

Once the concentrations at the biota access locations are determined, potential exposures from consumption and use of the water may be determined for seven bodily organs. These include whole body, bone, liver, thyroid, kidney, lung, and the gastro-intestinal (GI) tract.

As discussed earlier, the calculational procedure first estimates the source term Jo, in curies/year, leaving the disposal cell. However, the concentrations of radionuclides at the biota access locations are also determined by the volume of water with which the released and migrating radionuclides are diluted. All other considerations being equal, the larger the volume of water with which the radionuclides are diluted, the lower the concentration of the radionuclides in the water. The dilution volume is a site-specific variable, and is dependent upon the attributes of the aquifer (thickness, flow rate, dispersivity, etc.), the distance from the release point (the further away from the release point, the greater the mixing that would likely occur), and man-made perturbations such as pumping water from a well.

Given the generic nature of the analysis in this environmental impact statement, reasonable yet conservative assumptions are made regarding the dilution volumes. For the first two biota access locations (intruder well and boundary well), released radionuclides are assumed to be diluted by a volume of water equal to that provided by natural percolation of rainwater upon the disposal area (about 87 acres). (At the reference facility, this volume of water is equal to 63,400 m^3.) Of this volume, the individual using the contaminated water is assumed to withdraw 7700 m^3/year (3.84 gpm), which represents the basic annual needs of a single person living in a rural area (See Appendix G).

For the population well, the dilution volume is assumed to correspond to the annual volume of water withdrawn from a water well pumping at a rate of 100 gpm (200,000 m^3/yr). Small farming communities that utilize ground water for their needs usually have wells that range from 100 gpm to 1,000 gpm depending on the population. For the surface water access location, a stream is assumed having a flow rate of about 5 ft^3/sec (4.5 x 10^6 m^3/yr). A stream having a flow rate of much below this value is unlikely to be used for human consumption.

5.2.1 Description of Base Case No Action Alternative

Base case radiological impacts are calculated for the three base cases summarized in Table 5.1. Case 1 illustrates the potential ground-water impacts of disposing base case waste forms under conditions which promote disposal facility instability

Table 5.1. Base Cases Considered

Case 1 - Base Case-Moderately Permeable Soils

- Regular shallow land burial (SLB) trench (reference site and base case facility design as set out in Appendix E).
- Waste spectrum 1
- SLB with a thin cap
- No segregation of wastes containing chelates
- No segregation of compressible wastes
- Random disposal of waste
- Layering used as an intruder barrier
- Site soils are assumed to have moderate permeability

Case 2 - Base Case-Highly Permeable Soils

- Regular SLB trench
- Waste spectrum 1
- SLB with a thin cap
- No segregation of wastes containing chelates
- No segregation of compressible wastes
- Random disposal of waste
- Layering used as an intruder barrier
- Site soils are assumed to have relatively high permeability

Case 3 - Base Case-Low Permeable Soils

- Regular SLB trench
- Waste spectrum 1
- SLB with a thin cap
- No segregation of wastes containing chelates
- No segregation of compressible wastes
- Random disposal of waste
- Layering used as an intruder barrier
- Site soils are assumed to have relatively low permeability

at a site having moderately permeable soils. Case 2 illustrates the same impacts at a site having highly permeable soils and Case 3 a site having low permeable soils. The three base cases are analyzed to illustrate the relative difference in impacts that may occur due to differences in site-specific ground-water flow conditions. Relative to Case 1, the site for Case 2 is assumed to experience lower leaching due to shorter contact times between percolating water and the disposed wastes, shorter ground-water travel times between the disposed waste and the aquifer, and lower ion exchange. Relative to Case 1, the site for Case 3 is assumed to experience higher leaching (longer contact times), larger ground-water travel times between the disposed waste and the aquifer, and higher ion exchange.

A comparison of the retardation coefficients, contact times and ground-water travel times between the waste and the aquifer assumed for the three cases is included as Table 5.2.

The radiological impacts calculated for Cases 1-3 are conservative but do provide a baseline of data against which potential costs and radiological impacts of alternatives may be assessed. As referred to in Table 5.1, the facility for Cases 1-3 is sited, designed and operated as previously described in Chapter 3 and as set out in detail in Appendix E. The waste is disposed of in a regular shallow land burial trench with a "standard" thin cap.

The waste disposed of at the site is assumed to be that characterized as Waste Spectrum No. 1. "Waste Spectrum 1" refers to the base case waste form--much of which is assumed to be in an easily compressible, readily degradable waste form with relatively high leaching characteristics. Filter sludges and resins are dewatered and little to no compaction is performed for compressible wastes. The waste form for solidified liquids is assumed to be half urea-formaldehyde and half cement. Some liquids--e.g., those from institutional waste generators--are shipped to the disposal facility using absorbents rather than being solidified. Wastes containing organic chemicals, chelating agents, or compressible materials are assumed to be mixed with the higher activity wastes. The waste is also assumed to be randomly disposed into the reference facility, and due to the readily degradable nature of much of the waste, severe subsidence problems are assumed to occur. The facility is assumed to be characterized by potholes and subsidence depressions, leading to sources of rainwater infiltration. Percolation into the waste cells is assumed to be twice as high as the surrounding undisturbed soils. Finally, results from the preceeding intruder analysis are also included such that the higher activity wastes requiring increased intruder protection are disposed on the bottom of the trench. Some wastes, not acceptable for disposal based on the intruder analysis results, are excluded from the analysis.

5.2.2 Costs and Impacts of Base Case No Action Alternative

The base case costs and impacts are summarized on the following three tables which show the impacts and costs for the three cases analyzed. Table 5.3 summarizes the maximum exposures received over 10,000 years for each of the seven organs considered in the analysis from each of the four biota access locations: (1) a well located onsite which is assumed to be used by a potential inadvertent intruder following the end of the active institutional control period, (2) a well located at the site boundary which is assumed to be used by a few individuals, (3) a well assumed to be located approximately 500 meters down-gradient from the disposal facility and used by a small population of about 100 persons, and (4) a small stream located about one kilometer down gradient of the disposal facility, and assumed to be used by a small population of about 300 persons. Also shown is the approximate time, to 10,000 years, that these exposures occur. All exposures listed are to individuals. Table 5.4 illustrates the Case 1 calculated exposures to whole body and thyroid for each of the access locations for a number of time periods after facility closure. Table 5.5 contains a summary of other costs and impacts associated with waste disposal, including short-term population doses due to waste processing and transportation; short-term occupational doses due to waste processing, transport, and disposal; incremental energy

Table 5.2 Comparison of Assumed Environmental Characteristics for Cases 1, 2, and 3

Property	Case 1	Case 2	Case 3
Retardation set used (NRET)	3	2	4
Retardation coefficients			
H-3	1	1	1
C-14	10	10	10
Fe-55	2640	1290	5400
Ni-59	1750	860	3600
Ni-63	1750	860	3600
Co-60	1750	860	3600
Sr-90	36	18	73
Nb-94	4640	2150	10,000
Tc-99	4	3	5
I-129	4	3	5
Cs-135	350	173	720
Cs-137	350	173	7200
U-235	3520	1720	7200
U-238	3520	1720	7200
Np-237	1200	600	2500
Pu-238	3520	1720	7200
Pu-239/240	3520	1720	7200
Pu-241	3520	1720	7200
Pu-242	3520	1720	7200
Am-241	1200	600	2500
Am-243	1200	600	2500
Cm-243	1200	600	2500
Cm-244	1200	600	2500
Infiltrating percolation factor:*	1.16E-3 3.24E-5	1.16E-4 3.24E-6	1.16E-2 3.24E-4
Ground-water travel time from bottom of waste to aquifer (yrs)	10	<<1	60

*This factor is equal to $p \times t_c$. Substituting for t_c, this factor is equal to p^2/nv, where

p = amount of the precipitation (m/yr) that infiltrates into a disposal cell and comes into contact with the waste.

$t_c = p/nv$ = percolation contact time with the waste.

n = waste cell effective porosity

v = speed of the percolating water

The first value for each case is for percolation through a disposal cell cover equivalent to natural percolation at the reference facility (180 mm/yr). The second value is for reduced percolation due to an improved disposal cell cover for which the integrity of the cover can be reasonably assumed. See Appendix G.

Table 5.3 Base Radiological Impacts for Cases 1-3

	(mrem/yr)						
Cases*	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(1)							
Intruder	3.044E+1	3.063E+0	3.044E+1	8.462E+2	3.044E+1	3.044E+1	3.044E+1
Well	(100)	(6,000)	(100)	(4,000)	(100)	(100)	(100)
Boundary	1.571E+2	3.061E+0	1.571E+2	8.462E+2	1.571E+2	1.571E+2	1.571E+2
Well	(70)	(6,000)	(70)	(4,000)	(70)	(70)	(70)
Population	4.434E-1	6,197E-1	2.121E-1	2.673E+2	3.887E-1	1.246E-1	2.839E-1
Well	(6,000)	(8,000)	(8,000)	(4,000)	(6,000)	(8,000)	(6,000)
Surface	1.781E-2	2.685E-2	7.190E-3	1.218E+1	1.526E-2	5.375E-3	1.040E-2
Water	(8,000)	(10,000)	(8,000)	(4,000)	(8,000)	(10,000)	(8,000)
(2)							
Intruder	9.505E+1	1.808E+0	9.498E+1	2.678E+2	9.504E+1	9.495E+1	9.501E+1
Well	(100)	(1,000)	(100)	(800)	(100)	(100)	(100)
Boundary	1.445E+2	1.620E+0	1.445E+2	2.678E+2	1.445E+2	1.445E+2	1.445E+2
Well	(70)	(2,000)	(70)	(2,000)	(70)	(70)	(70)
Population	5.538E-2	1.058E-1	3.210E-2	2.675E+1	4.991E-2	2.124E-2	3.943E-2
Well	(6,000)	(6,000)	(6,000)	(6,000)	(6,000)	(6,000)	(6,000)
Surface	2.988E-3	7.152E-3	1.926E-3	1.219E+0	2.731E-3	1.432E-3	2.242E-3
Water	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
(3)							
Intruder	9.344E+1	7.529E+0	9.344E+1	8.025E+2	9.344E+1	9.344E+1	9.344E+1
Well	(100)	(6,000)	(100)	(900)	(100)	(100)	(100)
Boundary	2.637E+1	7.266E+0	2.637E+1	8.246E+2	2.637E+1	2.637E+1	2.637E+1
Well	(120)	(6,000)	(120)	(2,000)	(120)	(120)	(120)
Population	1.025E+0	5.014E+0	1.010E+0	6.508E+2	1.022E+0	1.003E+0	1.014E+0
Well	(10,000)	(10,000)	(10,000)	(4,000)	(10,000)	(10,000)	(10,000)
Surface	4.314E-2	1.947E-1	4.029E-2	3.522E+1	4.243E-2	3.896E-2	4.108E-2
Water	10,000)	(10,000)	(10,000)	(4,000)	(10,000)	(10,000)	(10,000)

*The radiological impact estimates shown for each access location are the maximum over 10,000 years as calculated using the GRWATER code. The second number, in parentheses, is the year after facility closure that the calculated impacts occur. The impacts are listed as obtained from the code output and should not be interpreted as representing accuracy to three significant digits.

Table 5.4 Summary of Case 1 Calculated Exposures to Whole Body and Thyroid as a Function of Time

Year Following Closure	Whole Body (mrem/yr) Intruder Well	Whole Body Boundary Well	Whole Body Population Well	Whole Body Surface Water	Thyroid (mrem/yr) Intruder Well	Thyroid Boundary Well	Thyroid Population Well	Thyroid Surface Water
40	9.775E+1	0	0	0	9.775E+1	0	0	0
50	5.012E+2	0	0	0	5.012E+2	0	0	0
60	2.854E+2	5.003E-1	0	0	2.854E+2	5.003E-1	0	0
70	1.625E+2	1.571E+2	0	0	1.625E+2	1.571E+2	0	0
80	9.257E+1	9.257E+2	0	0	9.257E+1	9.257E+1	0	0
90	5.272E+1	5.272E+1	0	0	5.272E+1	5.272E+1	0	0
100	3.044E+1	3.002E+1	0	0	3.044E+1	3.002E+1	0	0
120	1.958E+1	9.741E+0	0	0	1.957E+1	9.741E+1	0	0
200	4.414E-1	4.349E-1	0	0	8.491E+1	8.487E+1	0	0
300	2.315E-1	1.197E-1	0	0	1.644E+2	8.459E+1	0	0
400	2.489E-1	2.364E-1	2.209E-7	0	1.692E+2	1.692E+2	2.209E-7	0
500	4.656E-1	2.369E-1	3.147E-9	0	2.539E+2	1.695E+2	3.147E-9	0
600	4.644E-1	3.548E-1	2.190E-11	0	2.539E+2	2.538E+2	2.190E-11	0
700	5.811E-1	5.160E-1	1.014E-13	0	3.384E+2	2.944E+2	1.014E-13	0
800	6.079E-1	5.798E-1	5.074E-16	1.625E-18	3.586E+2	3.384E+2	5.074E-16	1.625E-18
900	6.967E-1	6.930E-1	2.108E-18	2.321E-20	4.230E+2	4.203E+2	2.108E-18	2.321E-20
1,000	8.006E-1	6.955E-1	8.965E-11	1.589E-22	4.973E+2	4.231E+2	6.416E-8	1.589E-22
2,000	1.460E+0	1.454E+0	2.235E-1	1.008E-19	8.461E+2	8.461E+2	1.600E+2	7.232E-17
4,000	1.618E+0	1.617E+0	3.851E-1	1.699E-2	8.462E+2	8.462E+2	2.673E+2	1.218E+1
6,000	1.695E+0	1.695E+0	4.434E-1	1.698E-2	8.462E+2	8.462E+2	2.673E+2	1.218E+1
8,000	7.549E-1	8.278E-1	3.998E-1	1.781E-2	2.200E+2	2.722E+2	2.155E+2	1.218E+1
10,000	3.880E-1	3.880E-1	1.226E-1	1.034E-2	2.623E+1	2.623E+1	8.290E+0	3.891E+0

Table 5.5 Other Impacts Associated With Cases 1-3

Impacts	Case 1	Case 2	Case 3
Short-term population exposures: (man-mrem)			
Processing at waste generator**	-	-	-
Processing at regional processing center	0	0	0
Waste tranportation	5.10E+5*	5.10E+5	5.10E+5
Short-term occupational exposures: (man-mrem)			
Processing at waste generator**	-	-	-
Processing at regional processing center	0	0	0
Waste transportation	5.82E+6	5.82E+6	5.82E+6
Waste disposal	2.46E+6	2.46E+6	2.46E+6
Waste generation and transport costs: ($)			
Processing at waste generator**	-	-	-
Processing at regional processing center	0	0	0
Waste transportation	2.05E+8	2.05E+8	2.05E+8
Disposal costs: ($)			
Design & Operational	1.88E+8	1.88E+8	1.88E+8
Postoperational	3.82E+7	3.46E+7	4.99E+7
Total	2.26E+8	2.23E+8	2.38E+8
Unit ($/m³)	231	227	243
Energy use: (gal)**	-	-	-
Land use: (m²)	3.40E+5	3.40E+5	3.40E+5
Waste volume disposed: (m³)			
Regular:			
Chemical-stable	9.26E+3	9.26E+3	9.26E+3
Chemical-unstable	1.15E+5	1.15E+5	1.15E+5
No chemical-stable	2.22E+5	2.22E+5	2.22E+5
No chemical-unstable	5.34E+5	5.34E+5	5.34E+5
Total	8.81E+5	8.81E+5	8.81E+5
Layered:			
Chemical-stable	9.62E+2	9.62E+2	9.62E+2
Chemical-unstable	1.87E+3	1.87E+3	1.87E+3
No chemical-stable	3.70E+2	3.70E+2	3.70E+2
No chemical-unstable	9.59E+4	9.59E+4	9.59E+4
Total	9.91E+4	9.91E+4	9.91E+4
Hot Waste Facility:	0	0	0
Total Disposed:	9.80E+5	9.80E+5	9.80E+5
Total volume not acceptable: (m³)	1.94E+4	1.94E+4	1.94E+4

*The notation 5.10 E+5 means 5.10×10^5

**In this chapter, population exposures due to waste processing by waste generators, occupational exposures due to waste processing by waste generators, costs due to waste processing by waste generators, and energy use are presented as impacts and costs in addition to those associated with waste spectrum 1.

use in terms of total gallons of fuel; and committed land use. Total costs and impacts from processing, transport, and disposal of an entire spectrum of waste over 20 years are listed.

Ground-Water Impacts

As shown in Tables 5.3 and 5.4 the calculated doses are high for the base case. For Case 1, maximum doses to all organs, with the exception of the thyroid and bone are about 30 millirem at the intruder well, exceed 150 mrem at the boundary well, are on the order of 0.1 mrem at the population well, and are on the order of 10^{-2} to 10^{-3} mrem at the surface body water. Thyroid doses are in the range of 800 mrem at the intruder and population wells, 270 mrem at the population well, and 12 mrem at the surface water body. It is not likely that doses to actual individuals could ever be this high, notwithstanding the conservatism of the analysis. For one thing, potholes and depressions would be filled in by the site owner, thus reducing the percolation. In addition, ground-water movement of radionuclides would almost certainly be detected through monitoring wells long before appreciable exposures could be received by the public. A more important point is that a considerable amount of effort and cost to the site owner may be required to prevent such exposures from occurring. This is discussed in more detail later.

Table 5.4 provides an illustration of potential whole body and thyroid doses for Case 1 as a function of time. Exposures to whole body at the intruder and boundary wells are principally due to tritium, which constitutes (on a curie basis) the largest part of the radionuclide inventory at the reference disposal facility. Tritium has the largest leach fraction of the radionuclides considered and is also assumed to migrate with the speed of the ground water. Given the nature of the assumptions in the calculations, tritium leaves the disposed waste more or less as a slug flow. Due to dispersion, however, the edges of the pulse trail out. As the slug of contamination moves past the intruder well and then the boundary well, potential exposures at each well rise to a maximum and then fall to another low value. Tritium, however, has a relatively short half-life and due to radioactive decay has only a very minor impact at the population well and surface water body.

However, total impacts are from all radionuclides, each of which may have a different leach rate, retardation coefficient, and decay constant. The maximum concentration of each radionuclide in ground water therefore arrives at the access location of interest at different times--often at widely different times up to thousands of years. For example, typically following the tritium would be Tc-99 and I-129, followed by C-14. If graphed, the result would be typically a lumpy dose curve. As shown in Table 5.4 after an initial hump within a few hundreds of years, a low period is observed after which one or more humps are observed in the range of thousands of years. An exception is the thyroid, which illustrates a broad maximum which persists for long time periods. This dose is mainly a result of iodine-129.

As shown in Table 5.4, the calculated maximum exposures at the intruder well over 10,000 years occur at about 50 years following facility closure and are in the range of 500 millirem. However, prior to the assumed end of the 100-year active institutional control period, the site owner would preclude inadvertent intrusion and possible construction and use of the intruder well. The maximum intruder well exposures for whole body are therefore determined to occur at about 100 years following disposal facility closure, or right at the assumed end of the active institutional control period. This results in larger whole body exposures at the boundary well than at the intruder well. Maximum thyroid exposures at the intruder well occur in the neighborhood of 4,000 years following facility closure.

Cases 2 and 3 illustrate the effect of some different assumptions regarding site-specific conditions. In Case 2, relatively low retardation coefficients are assumed, indicative of a sandy soil. The same sandy soil is used as a backfill around the waste packages, resulting in a reduced contact time with infiltrating rainwater. In Case 3, on the other hand, the soils in which the waste is disposed are assumed to be relatively impermeable, and have higher retardation coefficients than that of the reference facility. However, the same relatively tight soils are assumed to be backfilled into the disposal trenches. This results in relatively higher contact times with infiltrating precipitation. As can be seen in Table 5.3, Case 2 seems to generally exhibit somewhat lower exposures than Case 1 for the population well and surface water body. The opposite trend appears to occur at these two access locations for Case 3. For the intruder well and the boundary well, a clear-cut trend is not seen. Calculated exposures for Cases 2 and 3 are sometimes higher, and sometimes lower, than those for Case 1, depending upon the organ considered. For thyroid exposures at the boundary well, for example, calculated potential maximum exposures for Case 2 are about a factor of 3 lower than for Case 1. These calculated exposures occur over a very long time period, however--i.e., over a broad flat curve lasting greater than 9,000 years. Maximum thyroid exposures for Case 3 are in the same range as those calculated for Case 1 but the time period over which the maximum exposures occur is less pronounced.

This should not be interpreted to conclude that disposal sites having extremely permeable soils are the best for waste disposal or that sites having very impermeable soils should be avoided. The point is the importance of minimizing the quantity of radionuclides released from the waste. After the radionuclides have been released from the waste, the control one has over potential exposures is diminished. One has to depend upon ion-exchange properties in soil--properties which are difficult to predict with certainty.

The relative impacts of other options regarding near-surface waste disposal--that of reducing the quantity of water infiltrating into the trench and of reducing the radioactivity mobilized by the infiltrating water--is discussed extensively in subsequent cases. Prior to this, however, base case costs and short-term radiological impacts are examined for the three cases. This provides a basis against which other options may be compared.

5.2.2.1 Other Impacts

Base case costs and short-term radiological impacts are shown in Table 5.5 and consist of waste processing and transportation exposures, occupational exposures, costs, incremental energy use, and land use. Also shown are the waste volumes disposed as well as individual and population intruder exposures to whole body and bone. Populational exposures from processing wastes at all generating facilities are not calculated for waste spectrum 1 as waste spectrum 1 is meant to represent conditions in which little or no waste processing is performed other than that required to meet safety requirements for transportation and disposal facility waste handling operations. In addition, such impacts are already considered as part of licensing such facilities. (This EIS is interested in the incremental exposures above the base case exposures.) Potential impacts from processing wastes at a regional processing center are also zero for the reference waste spectrum 1. (No regional waste processing is assumed to occur for waste spectrum 1.)

Total transportation population exposures are an estimated 510,000 man-millirem for 20 years delivery of waste to the disposal facility. This exposure was calculated assuming an average waste transport distance of 400 miles (one way) and an assumed population dose of 0.018 man-millirem per shipment per mile. In addition, each shipment is assumed to make one stop during the 400-mile trip, resulting in a population dose of 2.0 man-mrem per shipment stopover. The total population exposed is assumed to be 1.5×10^5 persons during transit and 500 persons per stopover.

Short-term occupational exposures are calculated as the total exposures over 20 years of (1) waste processing activities, (2) waste transportation, and (3) waste disposal. Occupational exposures from normal waste handling and packaging to meet DOT transportation requirements and to meet safety requirements at disposal facilities (e.g., specific packaging criteria for biological wastes, solidification of liquids) are not estimated for waste spectrum 1. These would be expected to vary widely among the many thousands of NRC and Agreement State licensees. However, additional potential exposures due to the additional waste treatment processes considered in waste spectra 2-4 are estimated as part of the impacts of these spectra. Occupational exposures due to waste transportation and waste disposal are estimated as about 5.82 and 2.46 man-millirem per m^3 of waste transported and disposed. Again, as no waste processing activities are assumed to take place at a regional processing center for waste spectrum 1, no occupational doses due to waste processing at the regional center are calculated for Cases 1-3.

Disposal facility occupational exposures are calculated as approximately 123,000 man-mrem/year. Assuming a total exposed working crew of about 45 persons, this calculates as an average estimated 2.73 rem per year per individual worker, which is within the general range of occupational exposures currently experienced at operating disposal facilities.

Costs are broken down into processing costs, transportation costs, and disposal costs. For waste spectrum 1, minimal waste processing is assumed to occur. The actual costs experienced by a waste generator are a function of many variables, including the characteristics of the waste processed, the volume of the waste processed, and the design of the waste processing equipment, if any. Processing costs are presented in this section as additional costs to those associated with waste spectrum 1.

Transportation costs may vary widely for different waste generators depending upon the distance from the waste generator to the disposal facility and the characteristics of the waste disposed. Information regarding the assumptions used to determine these costs are provided in Appendix G. For this EIS, a base case transportation cost of $205 million is estimated for transportation of about 50,000 m^3 of waste per year over 20 years ($209.2 per m^3 of waste).

Disposal costs are calculated in two parts: design and operational costs and postoperational costs. Design and operational costs are the fees charged by the disposal facility operator to pay for operating and overhead costs, and receive a return on investment. These costs are estimated at about $192/$m^3$ ($5.43/$ft^3$), which is about 18 cents/ft^3 higher than that presented in Table 4.3 for the reference facility. This is due to the assumption of the additional operational step of layering the higher activity waste to reduce potential intruder impacts.

Postoperational costs are fees assumed to be charged to the waste generator to ensure that sufficient funds will be available for facility closure and for long-term care, and are calculated as described in Appendix Q. As discussed in Appendix Q, funds for closure are assumed to be provided by the disposal facility licensee, but passed on to the disposal facility customers. The availability of sufficient funds for closure is assumed to be assured through a financial surety mechanism. Funds for 100 years of long-term care are assumed to be provided through a state-operated sinking fund. As shown, unit post-operational costs can, depending upon the case considered, range from $35/$m^3$ ($1.00/$ft^3$) to $51/$m^3$ ($1.44/$ft^3$).

The shear magnitude of the funds that would be needed to be collected over 20 years to ensure long-term care for the first three cases deserves special consideration--e.g., $50 million for Case 3. As discussed earlier, significant potential ground-water doses are estimated. These large calculated exposures result from the assumed practice of indiscriminately disposing of easily compressible, degradable waste streams (which frequently have only very low levels of contamination) with higher activity waste streams. These easily degradable waste streams (e.g., trash) frequently contain chemicals which may increase leaching and reduce sorption (ion exchange) of radionuclides during migration through ground water. As discussed earlier, these calculated levels of exposures are not likely to be actually realized. However, to prevent such potential exposures from occurring, a considerable amount of active site maintenance would be expected on the part of the site owner. It is difficult to predict how long this extensive site maintenance would be required or how much it would cost, although it is seen that many millions of dollars could be potentially involved.

It could be argued that it would be a simple matter to merely charge sufficient postoperational fees to provide for the required care. However, this concept has a number of drawbacks, including:

- There is no assurance that sufficient funds will be available for long-term care, or that funds collected will not be spent for other purposes. For example, the disposal facility may close prematurely and prior to collection of sufficient funds.

- o There is no assurance that the extensive kinds of maintenance activities that would be required would actually be carried out in a timely manner. For example, at a site with very impermeable soils, subsidence could lead to disposal trenches filling up with water (the bathtub scenario), which could potentially be ignored until large expenditures were required to rectify the problem.

- o Extensive site maintenance activities can lead to releases of quantities of radionuclides offsite. For example, if extensive water management activities such as removal and evaporation of large quantities of trench leachate are required (see Appendix Q), then offsite exposures will result. EPA has estimated that the potential impacts to a maximum exposed individual near a disposal facility evaporating about a million gallons of contaminated liquid per year to be in the neighborhood of 20 mrem (whole body) per year (Ref. 4).

Leaving a disposal facility in a condition so that extensive active maintenance activities are required to ensure public health and safety could result in a considerable financial burden to the site owner and to future generations.

Also shown in Table 5.5 is the estimated land use (3.4 E+5 m^2, or about 86 acres) to dispose of approximately one million m^3 of waste. In this chapter, energy use is presented in incremental gallons of equivalent fuel from that associated with Cases 1-3.

5.2.3 Need for Action

Based upon the results of the preceeding base case analysis and upon a review of existing experience and data regarding ground-water migration, a need for regulatory action is clearly indicated. That is, the no-action alternative is clearly unacceptable. For the further development of performance objectives and technical criteria to minimize potential ground-water impacts, four key factors can be set out:

1. Ground-water migration is very site-specific and depends on the meteorological, hydrological and geological conditions of the site;

2. Ground-water migration is enhanced by an unstable waste form which can lead to waste decomposition, trench collapse, and increased water infiltration. The long-term effects of an unstable waste form and resulting unstable site conditions are difficult to predict;

3. Unstable site conditions at some sites can lead to remedial action programs directed at minimizing potential long-term environmental releases. The programs can result in short-term environmental releases, considerable expenditures of funds which were not planned for at the time the facility was opened, and the possibility that such "active maintenance" programs will have to be carried out over an uncertain time period at uncertain high costs;

4. The potential for migration is increased by the extended contact of water with waste both during operations and after closure.

It is also apparent that potential long-term groundwater migration cannot be analyzed by only considering potential radiological impacts. The need for long-term social commitment to care for sites over the long term and to maintain potential radiological impacts to low levels must also be considered. Two related concepts which impact upon the potential for long-term radiological releases and upon the need for long-term social commitment are: (1) the stability of the waste form and disposal site, and (2) the predictability of the potential radiological impacts. Unless the waste and the disposal site are stable over time, it is difficult to predict the long-term radiological impacts of disposal, or the activities (maintenance, monitoring, etc.) and associated costs required to maintain potential impacts to low levels. If long-term radiological impacts and activities required by a site owner cannot be predicted, then it is difficult to assure the long-term protection of public health and safety, or to assure that future generations will not be burdened by large expenses to maintain a disposal site in a safe condition.

The unpredictable nature of waste/disposal site instability can lead to increased radiological and economic impacts at both humid and arid sites. At humid sites, stable disposal cell covers are needed to minimize water infiltration through the covers and thus maintain potential ground-water releases to levels as low as reasonably achievable. In cohesive, poorly drained soils the inherent longer contact time of infiltrating water leads to greater expected corrosion and decomposition rates than in well-drained permeable soils where the contact time would be less. One is basically trading greater leaching and higher ion-exchange rates in low permeable soils with smaller leaching (lower contact times) and lower ion-exchange rates in higher permeable soils. Waste instability in poorly drained soils can especially lead to a potential "bathtub" problem, which can further lead to costly trench pumping and site stabilization programs. In arid sites, trench instability can lead to subsidence and increased plant and animal intrusion plus increased potential for wind erosion and dispersion of trench contents. For example, at a government-operated disposal facility located on the arid Hanford Reservation, there was an occurrence in which boxes of disposed waste collapsed, resulting in a depression in the trench cover which exposed disposed waste. Portions of this exposed waste were subsequently dispersed by high winds.

Three factors contribute to waste form/disposal site instability, the contact of water with waste, and the resulting long-term radiological and economic consequences.

- o site environment;
- o site design and operations; and
- o waste form.

To consider the maximum potential impacts from waste disposal, the base case site analyzed is a humid site, although as stated above, waste/site instability is also important at arid sites. Variations to site designs and operating practices can lead to greater site stability and minimize long-term migration.

Some of these variations include: (1) segregation of compressible wastes and wastes containing large quantities of organic chemicals or chelating agents, (2) thicker, less permeable disposal cell covers, (3) improved compaction of disposal cell covers, (4) stacked disposal of waste rather than random disposal, (5) grouting of disposed wastes, and (6) use of engineered structures such as concrete walled trenches.

The waste form is probably the most significant factor contributing to site stability--a factor containing the paradox that much if not most of the problems with site instability and high maintenance costs is caused by the wastes containing the least activity. Most of the waste sent to LLW disposal facilities consists of very low activity material such as trash which is frequently easily degradable. In the past, some of this waste has been packaged in easily degradable packages such as card board boxes. Most of the waste, however, is currently packaged in longer lasting, but still degradable, rigid containers such as wooden boxes and 55-gallon steel drums. Large void spaces can also exist within waste packages and the disposal cells after waste disposal. As the waste material degrades and compresses, a process which is accelerated by contact by water, additional voids are produced. This leads to settlement of the disposal cell contents, followed by subsidence or slumping of the disposal cell cover. This increases the percolation of water into disposal cells, accelerating the cycle. This slumping and subsidence is frequently quite sudden.

The use of the rigid containers would be expected to reduce the amount of short-term subsidence. Over the longer term, however, subsidence problems would still be observed, and factors contributing to this include: (1) the waste contained in the rigid containers is still frequently easily degradable, and (2) even if the waste is not readily degradable (e.g., activated alloy metal), it is frequently packaged into containers so that large voids are left within the containers. The rigid containers initially provide some structural support to the disposal cell covers, and act to "bridge" voids within the disposal cell and waste packages. (These voids may exist initially within the disposal cell and waste packages or may be produced as a result of waste decomposition.) Eventually, however, this structural support is lost as the rigid containers rust or rot out, leading to disposal cell settling at rates which are difficult to predict. The basic problem is the voids. If a waste container were completely filled with relatively nondegradable, noncompressible materials--e.g., activated metal with void spaces within the container filled with sand--then degradation of the waste package would not be expected to result in a subsidence problem.

In the following section, a number of cases are analyzed to investigate the cost-effectiveness of different ways in which to achieve improved disposal facility stability, reduce radionuclide migration, and minimize long-term social commitment in carrying out active maintenance programs. In these cases, the reference disposal facility (moderately permeable soils,) is assumed. The potential relative costs and impacts of variations in disposal facility design and operating practices are first investigated, followed by the potential relative costs and impacts of improvements in waste form.

5.2.4 Alternatives to the Base Case

The following description of alternatives considers a wide range of potential improvements that can be applied to design and operations to improve waste and site stability and to reduce the contact of waste by water. Eight major cases are examined, with variations on some cases also examined as appropriate. These cases include the following:

Case 1A - Use of sand backfill
Case 4 - Operationally improved case
Case 5 - Concrete walled trenches
Case 6 - Decontainerized disposal of compressible waste
Case 7 - Use of improved waste forms
Case 8 - Use of further improved waste forms
Case 9 - Walled trenches and further improved waste forms
Case 10 - High integrity containers

Case 1A is included to illustrate use of a sand backfill around waste packages to minimize contact time of percolating water with disposed waste. The disposal facility design and operating practices are assumed to be identical to Case 1. Waste spectrum 1 is also assumed.

Case 4 is included to illustrate a range of improvements to disposal facility design and operation without improvements in waste form. This case is composed of 5 subcases in which successive additional disposal facility design options are added, including (in order): waste segregation, improved compaction of the disposal cell cover, a thick clay cover, stacking of waste, and use of a hot waste facility.

Case 5 involves use of a highly engineered disposal technique to provide disposal facility stability. The waste is segregated, stacked within concrete walled trenches, and then grouted in place. A concrete trench floor and a one meter thick concrete cap is also provided in addition to a thick compacted clay cap. This case--a concrete walled trench--would be expected to involve costs similar to an above-ground engineered structure.

Case 6 is included to examine an alternative method of disposing of compressible wastes other than by extensive pretreatment operations. In this case, compressible wastes are delivered to the disposal facility in reusable containers. At special (segregated) trenches, the wastes are emptied out and compacted by heavy machinery. The wastes are periodically covered by a soil layer which is also compacted. To eliminate wind scatter, operations are conducted under an air support building.

This alternative is assumed to require a presorting operation to exclude sealed sources, activated metal, or other high radiation sources. Even so, worker exposures for such operations are expected to be high. The advantage of this operation is that since there are no rigid containers and trench voids are reduced, it may be possible to arrive at a stable site within a few years. However, higher maintenance activities would be initially expected until stability is achieved.

Case 7 is similar to Case 4 except that an improved waste form is used--i.e., waste spectrum 2. This spectrum represents a number of improved waste forms which can be implemented in a reasonably short time period. All liquids, filter sludges, and resins are solidified in improved waste forms (half cement and half synthetic polymer). Compressible wastes are compacted, which results in an improved waste form for these wastes. Higher activity wastes such as LWR noncompactible trash are packaged in a manner which resists compression over the long term.

This case consists of four subcases. Case 7A is similar to Case 1A in that the waste packages are assumed to be disposed without consideration of segregated disposal of compressible wastes and wastes containing organic chemicals or chelating agents. Cases 7B, 7C, and 7D are similar to Cases 4A, 4B, and 4C and include the following successive disposal facility design options: waste segregation, improved compaction of the disposal cell covers, and use of a thicker clay cover.

Case 8 is similar to Case 7D except that a further improved waste form is used--i.e., waste spectrum 3. This spectrum represents about the best overall waste form which can be reasonably implemented using existing technology. However, it is expensive and requires time to implement. In this spectrum, compressible wastes are incinerated and solidified. Liquids, resins, and filter sludges are also solidified. The solidification media is assumed to be a synthetic polymer. This spectrum generally provides a very stable waste form. This case represents minimal impacts and long-term maintenance costs at relatively high waste treatment costs.

Case 9 is similar to Case 5 and is included to illustrate use of extreme (expensive) measures to minimize migration and long-term maintenance requirements. Stability is achieved by both the waste form (waste spectrum 3) and the disposal operations (walled and grouted disposal trenches).

Case 10 is included to illustrate use of high-integrity containers (HICs) to package and dispose of certain waste streams. Case 10 consists of three subcases using similar disposal facility designs as Cases 4C and 7D.

5.2.4.1 Case 1A - Use of Sand Backfill

The following cases investigate use of a number of options for waste form, waste packaging, and disposal facility design and operation to increase disposal facility stability and to minimize radionuclide migration. To do this, the cases principally investigate methods to reduce percolation of water into disposal cells and/or reduce migration of radionuclides from disposed waste streams through improved waste forms (e.g., through solidification) or packaging.

Case 1A, on the other hand, follows from Case 2 and investigates use of a sand backfill around disposed waste packages. This reduces the contact time of percolating water and therefore reduces leaching of radionuclides from the waste packages. Since the sand fill would tend to readily flow into interstitial spaces between waste packages during backfill operations, some reduction in trench voids would also be expected to occur. The potential usefulness of this technique was previously alluded to during the discussion on Cases 1-3.

For Case 1A, the disposal facility design is assumed to be essentially the same as Case 1, and is summarized on Table 5.1. Waste packages are randomly disposed into disposal cells, with no segregation of compressible waste streams or waste streams containing organic chemicals or chelating agents. A thin earth cover is placed over the disposed wastes, and is subjected to indifferent compaction. Instead of backfilling the disposal cells with excavated soil, however, a clean sand fill is used for this purpose. In addition, a 0.3 m (1 ft) thick layer of sand is placed on the bottom of the disposal cell prior to waste emplacement. The waste is emplaced to within one meter of the top of the disposal cell, and then backfilled with sand to the level of the top of the cell. The cap is then emplaced. The sand fill is assumed to be obtained from a local borrow area and is stockpiled onsite until used.

Ground-Water Impacts

Ground-water impacts for Case 1A are shown in Table 5.6. In comparison with Case 1, use of the sand backfill reduces maximum ground-water impacts by about a factor of 10. In the analysis, the contact time is calculated as follows:

$t_c = \rho/nv$, where

p = the precipitation (m/yr) that infiltrates into a disposal cell and comes into contact with the disposed waste.

n = waste disposal cell effective porosity

v = speed of the percolating water (m/yr)

Table 5.6 Maximum Ground-Water Impacts Associated with Case 1A

Case	(mrem/yr) Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(1A)							
Intruder Well	3.044E+0 (100)	3.063E-1 (6,000)	3.044E+0 (100)	8.462E+1 (4,000)	3.044E+0 (100)	3.044E+0 (100)	3.044E+0 (100)
Boundary Well	1.571E+1 (70)	3.061E-1 (6,000)	1.571E+1 (70)	8.462E+1 (4,000)	1.571E+1 (70)	1.571E+1 (70)	1.571E+1 (70)
Population Well	4.845E-2 (10,000)	7.115E-2 (10,000)	2.516E-2 (10,000)	2.674E+1 (8,000)	4.290E-2 (10,000)	1.432E-2 (10,000)	3,229E-2 (10,000)
Surface Water	2.190E-3 (10,000)	3.166E-3 (10,000)	1.128E-3 (10,000)	1.219E+0 (10,000)	1.934E-3 (10,000)	6.345E-4 (10,000)	1.445E-3 (10,000)

For the reference disposal facility soils, a waste disposal cell effective porosity of about 25% is conservatively assumed. The speed of the percolating water is assumed to be about one foot per day, which corresponds to a permeability of about 10^{-4} cm/sec. For the sand backfill, the speed of the percolating water is assumed to be raised to about 10 ft/day.

Although lower impacts are calculated for this case, it should be recognized that the sand backfill can be a useful conjunction to a stable disposal facility but cannot be a replacement to a stable disposal facility. For one reason, the use of the backfill is effective for only so long as the percolating water can drain through the bottom of the disposal cells. If the rate at which the water drains through the bottom of the disposal cells is less than the percolation rate, water will tend to collect in the bottom of the disposal cells. If sufficient water collects to inundate the disposed waste packages, then of course the advantage of using the sand backfill is lost. As discussed previously, for Cases 1-3, this may especially be of concern for disposal facilities having highly impermeable soils. This "bath tub" scenario may potentially lead to over flow of leachate from disposal cells. At the least, it will lead to considerably higher long-term maintenance activities and costs.

Other Impacts

Other impacts associated with this case are listed in Table 5.7. Compared with Case 1, the principal change is in disposal costs. Design and operation costs are raised from \$188 million to \$195 million, total disposal costs raised from \$226 million to \$233 million, and unit costs raised from \$231/m^3 to \$238/m^3. Since the use of the sand backfill is not believed to materially increase the stability of the disposal facility, long-term care costs are still projected to be at a high level. Energy use is also raised somewhat.

5.2.4.2 Case 4 - Operationally Improved Case

Case 4 examines the costs and impacts associated with a range of moderate facility operational changes which are intended to improve site stability and reduce percolation. The waste form is assumed to be unchanged from Cases 1-3. The five subcases of Case 4 are summarized in Table 5.8. Relative to the reference facility in Case 1A, the following operational changes are made in each of the 5 subcases of Case 4:

Case 4A. In this case, easily compressible waste streams as well as waste streams containing significant quantities of chelating agents are assumed to be disposed in a segregated manner (e.g., separate disposal trenches) from other waste streams.

Case 4B. In addition to segregation of the compressible waste streams and waste streams containing chelating agents, the disposal trench covers containing unstable waste streams are assumed to be subjected to improved compaction techniques.

Case 4C. This case is similar to Case 4B except that improved disposal trench covers are assumed to be emplaced, which are also subjected to improved compaction techniques.

Table 5.7 Comparison of Other Impacts Associated with Case 1A

Short-term population exposures: (man-mrem)	
Processing at waste generator	-
Processing at regional processing center	0
Waste transportation	5.10E+5
Short-term occupational exposures: (man-mrem)	
Processing at waste generator	-
Processing at regional processing center	0
Waste transportation	5.82E+6
Waste disposal	2.46E+6
Waste generation and transport costs: ($)	
Processing at waste generator	-
Processing at regional processing center	0
Waste transportation	2.05E+8
Disposal costs: ($)	
Design and operation	1.95E+8
Postoperational	3.82E+7
Total	2.33E+8
Unit ($/m^3)	238
Energy use: (gal)	+2.00E+5
Land use: (m^2)	3.40E+5
Waste volume disposed: (m^3)	
Regular:	
Chemical-stable	9.26E+3
Chemical-unstable	1.15E+5
No Chemical-stable	2.22E+5
No Chemical-unstable	5.34E+5
Total	8.81E+5
Layered:	
Chemical-stable	9.62E+2
Chemical-unstable	1.87E+3
No Chemical-stable	3.70E+2
No Chemical-unstable	9.59E+4
Total	9.91E+4
Hot Waste Facility:	0
Total Disposed	9.80E+5
Total not acceptable: (m^3)	1.94E+4

Table 5.8 Five Subcases of Case 4

Case 4A - Operationally Improved Case: Segregation

- o Regular SLB trench
- o Waste spectrum 1
- o SLB with a thin cap
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 4B - Operationally Improved Case: Segregation plus Compaction

- o Regular SLB trench
- o Waste spectrum 1
- o SLB with a thin cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 4C - Operationally Improved Case: Segregation, Compaction, and Improved Covers

- o Regular SLB trench
- o Waste spectrum 1
- o SLB with a thicker clay cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 4D - Operationally Improved Case: Segregation, Compaction, Improved Covers, Stacked Disposal

- o Regular SLB trench
- o Waste spectrum 1 SLB with a thicker clay cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Stacked disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 4E - Operationally Improved Case: Hot Waste Facility

- o Regular SLB trench
- o Waste spectrum 1
- o SLB with a thicker clay cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Stacked disposal of waste with a sand backfill
- o Hot waste facility for problematical wastes
- o Layering used as an intruder barrier for other wastes.

Case 4D. This case is similar to Case 4C except that instead of random disposal, the waste is assumed to be stacked in the disposal cells.

Case 4E. This case is included to investigate the costs and impacts of addition of a "hot waste facility" to dispose of some high activity waste streams which would otherwise be excluded from near-surface disposal. In this case, the hot waste facility is assumed to be a cement walled trench. Except for the assumed addition of the hot waste facility, this case is identical to Case 4D.

Ground-Water Impacts

Estimated maximum ground-water impacts at each of the access locations considered for each of the 5 subcases of Case 4 are summarized in Table 5.9. As shown, for each improvement in disposal facility design and operation, generally reduced ground-water impacts are observed. Over Cases 4A through 4D, whole body exposures drop from 0.8 mrem/yr to 0.02 mrem/yr at the intruder well, from 4 mrem/yr to 0.07 mrem/yr at the boundary well, from 0.05 mrem/yr to 0.005 mrem/yr at the population well, and from 0.002 mrem/yr to 2. E-4 mrem/yr at the surface water access location. Similarly, thyroid exposures drop from 80.5 mrem/yr to 8.3 mrem/yr at the intruder and boundary wells, from 25.4 mrem/yr to 2.6 mrem/yr at the population well, and from 1.2 mrem/yr to 0.1 mrem/yr at the surface water access location.

Relative to Case 1A, lower exposures are calculated for Case 4A for the intruder and boundary wells, resulting from segregation of the stable waste streams from the unstable waste streams and waste streams containing organic chemicals or chelating agents. Lower exposures (than Case 1A) are also observed at the other two access locations: the population well and the surface stream.

In Cases 1-3 and 1A, since all waste streams are mixed together during disposal, all streams experience high (twice natural percolation) percolation rates. Leaching of all solidified waste forms is enhanced by the presence of organic chemicals and chelating agents and the retardation coefficients of the migrating radionuclides are reduced (e.g., from NRET = 3 to NRET = 2, see Appendix G). In Case 4A, however, the stable waste streams are segregated from unstable streams and wastes containing significant quantities of chelating agents and organic chemicals are also disposed in a segregated manner. In this case, since the disposal cells containing the stable waste streams would not experience significant subsidence problems, percolation into these disposal cells is reduced (to the natural percolation of the disposal facility site). The disposal cells containing the compressible waste streams, however, still experience the higher (twice natural percolation) percolation rates. Similarly, the increased leaching of solidified wastes and reduced ion-exchange capacity (reduced retardation) is applied only to the segregated waste streams in the disposal cells containing significant quantities of chelating agents and organic chemicals.

It should be noted that about 76% of the wastes in waste spectrum 1 are in an unstable waste form, including higher activity waste streams such as LWR ion exchange resins (P-IXRESINS and B-IXRESINS) and industrial radioisotope

Table 5.9 Estimated Maximum Radiological Ground-Water Impacts for Cases 4A Through 4E.

	(mrem/yr)						
Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(4A)							
Intruder Well	7.719E-1 (100)	2.931E-1 (6,000)	7.719E-1 (100)	8.051E+1 (4,000)	7.719E-1 (100)	7.719E-1 (100)	7.719E-1 (100)
Boundary Well	3.985E+0 (70)	2.929E-1 (6,000)	3.985E+0 (70)	8.051E+1 (4,000)	3.985E+0 (70)	3.985E+0 (70)	3.985E+0 (70)
Population Well	4.617E-2 (10,000)	6.805E-2 (10,000)	2.401E-2 (10,000)	2.544E+1 (10,000)	4.091E-2 (10,000)	1.369E-2 (10,000)	3.084E-2 (10,000)
Surface Water	2.087E-3 (10,000)	3.028E-3 (10,000)	1.077E-3 (10,000)	1.160E+0 (10,000)	1.844E-3 (10,000)	6.068E-4 (10,000)	1.380E-3 (10,000)
(4B)							
Intruder Well	7.654E-1 (100)	1.661E-1 (6,000)	7.654E-1 (100)	4.541E+1 (4,000)	7.654E-1 (100)	7.654E-1 (100)	7.654E-1 (100)
Boundary Well	3.952E+0 (70)	1.660E-1 (6,000)	3.952E+0 (70)	4.541E+1 (4,000)	3.952E+0 (70)	3.952E+0 (70)	3.952E+0 (70)
Population Well	2.607E-2 (10,000)	3.855E-2 (10,000)	1.358E-2 (10,000)	1.435E+1 (6,000)	2.310E-2 (10,000)	7.756E-3 (10,000)	1.743E-2 (10,000)
Surface Water	1.179E-3 (10,000)	1.715E-3 (10,000)	6,088E-4 (10,000)	6.540E-1 (10,000)	1.041E-3 (10,000)	3.437E-4 (10,000)	7.796E-4 (10,000)
(4C)							
Intruder Well	2.487E-2 (6,000)	4.517E-2 (6,000)	2.156E-2 (100)	1.238E+1 (4,000)	2.235E-2 (6,000)	2.156E-2 (100)	2.156E-2 (100)
Boundary Well	1.113E-1 (70)	4.503E-2 (6,000)	1.113E-1 (70)	1.238E+1 (4,000)	1.113E-1 (70)	1.113E-1 (70)	1.113E-1 (70)
Population Well	7.096E-3 (10,000)	1.045E-2 (10,000)	3.690E-3 (10,000)	3.911E+0 (6,000)	6.287E-3 (10,000)	2.103E-3 (10,000)	4.739E-3 (10,000)
Surface Water	3.147E-4 (10,000)	4.347E-4 (10,000)	1.594E-4 (10,000)	1.783E-1 (10,000)	2.773E-4 (10,000)	8.713E-5 (10,000)	1.060E-4 (10,000)
(4D)							
Intruder Well	1.643E-2 (6,000)	2.933E-2 (6,000)	1.437E-2 (100)	8.252E+0 (4,000)	1.474E-2 (6,000)	1.437E-2 (100)	1.437E-2 (100)
Boundary Well	7.420E-2 (70)	2.923E-2 (6,000)	7.420E-2 (70)	8.252E+0 (6,000)	7.420E-2 (70)	7.420E-2 (70)	7.420E-2 (70)
Population Well	4.697E-3 (10,000)	6.799E-3 (10,000)	2.426E-3 (10,000)	2.607E+0 (10,000)	4.157E-3 (10,000)	1.368E-3 (10,000)	3.126E-3 (10,000)
Surface Water	2.084E-4 (10,000)	2.829E-4 (10,000)	1.049E-4 (10,000)	1.188E-1 (6,000)	1.835E-4 (10,000)	5.671E-5 (10,000)	1.359E-4 (10,000)

Table 5.9 (continued)

Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
	(mrem/yr)						
(4E)							
Intruder Well	1.645E-2 (6,000)	2.947E-2 (6,000)	1.437E-2 (100)	8.252E+0 (4,000)	1.477E-2 (6,000)	1.437E-2 (100)	1.437E-2 (100)
Boundary Well	7.420E-2 (70)	2.937E-2 (6,000)	7.420E-2 (70)	8.252E+0 (6,000)	7.420E-2 (70)	7.420E-2 (70)	7.420E-2 (70)
Population Well	4.703E-3 (10,000)	6.829E-3 (10,000)	2.432E-3 (10,000)	2.607E+0 (6,000)	4.163E-3 (10,000)	1.374E-3 (10,000)	3.132E-3 (10,000)
Surface Water	2.087E-4 (10,000)	2.841E-4 (10,000)	1.051E-4 (10,000)	1.188E-1 (6,000)	1.837E-4 (10,000)	5.695E-5 (10,000)	1.362E-4 (10,000

production wastes (N-ISOPROD). Therefore, the effectiveness of segregated disposal of stable waste streams is not as significant as it would be if the higher activity waste streams were stabilized. This is especially observed in the thyroid exposures, which are principally the result of iodine-129. In the waste source data base used in this EIS, most of the iodine-129 is estimated to be contained in the 7 LWR process waste streams (P-IXRESIN, P-FSLUDGE, P-CONCLIQ, P-FCARTRG, B-IXRESIN, B-CONCLIQ, B-FSLUDGE). Of these, only the P-CONCLIQ and B-CONCLIQ waste streams are in a stable form in waste spectrum 1.

In Case 4B, the covers of the disposal cells containing the segregated compressible waste streams are subjected to improved compaction using heavy machinery such as a vibratory compactor. This is an inexpensive additional operational step and results in an estimated reduction of migration from the unstable cells by a factor of about 2. This results in a minor reduction in whole body exposures and a more significant reduction (by a factor of about 2) of thyroid exposures at the intruder and boundary wells. This is because most of the boundary well whole body dose is due to tritium, and most of the tritium delivered to the reference disposal facility is contained in two relatively small volume waste streams (N-TRITIUM and N-TARGETS). These streams are already assumed to be stable, and because stable waste streams are segregated and disposal cells containing stable waste streams are not subjected in Case 4B to the improved compaction, there is no reduction (relative to Case 4A) in percolation into the disposal cells. This effect is not seen at the other two access locations due to the extensive decay of the tritium before the contaminated ground water reaches the other two access locations (The ground-water travel times between the boundary well and the other two access locations are 334 years for the population well and 734 years for the surface water.)

However, since most of the iodine-129 is contained in unstable waste streams, compacting the disposal cells containing the unstable waste streams results in a more significant reduction in thyroid dose at the intruder and boundary wells.

Since iodine-129 has a very long half life, a similar relative reduction in thyroid dose relative to Case 4A is seen for the population well and the surface water.

In Case 4C, additional clay soil is assumed to be transported to the disposal facility from an offsite borrow area. This clay soil is emplaced and compacted in relatively thin (8 to 12 inch) layers over the disposal cells containing the unstable waste streams, raising the thickness of the disposal cell covers by two meters. The same thickness of compacted clay soil is placed over the disposal cells containing the stable waste streams. As a result, during the 100 year active institutional control period, percolation into the disposal cells containing the segregated stable waste streams is assumed to be reduced to 30 mm, while the percolation into the disposal cells containing the compressible waste streams is reduced to 60 mm. Compared to Case 4B, then, overall percolation into the disposal cells is reduced by a factor of about 6. However, at the end of the active institutional control period, a breakdown in institutional controls is assumed to occur. At this point, due to intrusion by humans, the percolation into 10% of the disposal cells is increased to 180 mm (the natural percolation of the site). The remainder of the disposal cells, due to intrusion by deep-rooted plants and burrowing animals, experience a general increase in percolation of twice the former value (i.e., 60 mm for the stable waste disposal cells and 120 mm for the unstable waste disposal cells).

The effects of this case are most seen in the boundary well exposures for the whole body and other organs (except thyroid). In the calculations, the percolation rate is squared (See Appendix G), and a reduction in the percolation by a factor of 6 into the disposal cells containing the stable waste streams results in an estimated reduction in tritium migration from the stable disposal cells by a factor of 36. Hence, whole body exposures due to tritium at the intruder and boundary wells are reduced by a factor of about 36. Considering that the full effectiveness of the additional compacted cover is only assumed for 100 years, this would appear to indicate that it only requires a relatively short hold-up of large quantities of tritium to considerably reduce potential boundary well exposures.

The reduction in impacts for whole body and other organs relative to Case 4B is less significant for the other two access locations. This is again due to decay of the tritium while being carried by ground water. Exposures at the population well and surface water access location are dominated by releases from the disposed unstable waste streams. As expected, since the waste streams containing most of the iodine-129 are still in an unstable form, thyroid exposures are reduced at each biota access location by about a factor of somewhat less than 4. In this case, thyroid exposures at the intruder and boundary wells and exposures to all organs at the other two access locations are dominated by the increased percolation rates experienced after the end of the active institutional control period.

Case 4D is similar to Case 4C with the exception that instead of random disposal, the waste containers are assumed to be neatly stacked into the disposal cells. Disposal efficiency is assumed to be increased by a factor of 1.5 from 0.5 to

0.75. In the calculations, the total volume of water percolating into the disposal cells is given by the percolation rate multiplied by the surface area of the disposal cells. Increasing the disposal efficiency by a factor of 1.5 reduces the surface area of the disposed waste by a factor of 1.5. This results in a calculated reduction in exposures at the 3 access locations by a factor of 1.5, as shown in Table 5.9.

As a result of the increased disposal efficiency, potential intruder impacts are also increased by a factor of 1.5. This results in one small volume (800 m^3 over 20 years) waste stream, L-NFRCOMP, being listed as unacceptable in Case 4D. Therefore, Case 4E investigates use of a "hot waste facility" for this waste stream. For this analysis, the hot waste facility is assumed to be a grouted cement walled trench. As can be seen in Table 5.9 only a minor increase in ground-water impacts are calculated from disposal of this waste stream within a hot waste facility.

Other Impacts

Other impacts for these cases are summarized in Table 5.10. Since waste spectrum one is used for the 5 subcases of Case 4, there is seen in Table 5.9 to be no change from the previously calculated values for several of the impact measures. These include population exposures for waste processing and transportation, occupational exposures due to waste processing, and costs due to waste processing and waste transportation. Other impacts and costs, however, are somewhat altered.

One example is occupational exposures. Waste transportation occupational exposures are the same in all subcases to those estimated for Cases 1-3 with the exception of Case 4D. In this case, the waste is assumed to be stacked in the disposal cells. This results in slightly higher intruder impacts, sufficient to make one stream, L-NFRCOMP, listed as unacceptable. This reduction in 800 m^3 of waste delivered to the site results in lower transportation occupational exposures for this case.

Disposal facility occupational exposures are calculated to be approximately 2.46 million man-millirem for Cases 4A through 4C, which is the same as that calculated for Cases 1 through 3, but rise to 5.21 million man-millirem for Cases 4D and 5.27 million man-millirem for Case 4E. The values calculated for Case 4A arise from the expectation that waste segregation is not expected to result in significant additional occupational exposures. Waste that would be contact-handled would still be contact-handled, while waste such as high activity resins that must be hoisted into place would still be handled in the same manner. The main difference is that the disposal facility would operate two or more disposal cells instead of one and there would have to be an additional determination at the time of waste receipt and inspection regarding the disposal status of the different waste forms. This determination, however, would not have to be performed in a radiation field. Additional exposures could result from the probable increased waste storage requirements, but most wastes thus stored would probably be of lower activity.

Table 5.10 Other Impacts Associated With Cases 4A Through 4E

Impacts	Case 4A	Case 4B	Case 4C	Case 4D	Case 4E
Short-term population exposures: (man-mrem)					
Processing at waste generator	-	-	-	-	-
Processing at regional processing center	0	0	0	0	0
Waste transportation	5.10E+5	5.10E+5	5.10E+5	4.94E+5	5.10E+5
Short-term occupational exposures: (man-mrem)					
Processing at waste generator	-	-	-	-	-
Processing at regional processing center	0	0	0	0	0
Waste transportation	5.82E+6	5.82E+6	5.82E+6	5.74E+6	5.82E+6
Waste disposal	2.46E+6	2.46E+6	2.46E+6	5.21E+6	5.27E+6
Waste generation and transport costs: ($)					
Processing at waste generator	-	-	-	-	-
Processing at regional processing center	0	0	0	0	0
Waste transportation	2.05E+8	2.05E+8	2.05E+8	2.01E+8	2.05E+8
Disposal costs: ($)					
Design and Operational	2.01E+8	2.01E+8	2.10E+8	2.22E+8	2.25E+8
Postoperational:	*	*	*	*	*
Total:	*	*	*	*	*
Unit ($/m³)	223-244	223-244	233-253	245-266	248-268
Energy use: (gal)	+3.00E+5	+3.00E+5	-	4.00E+5	-2.00E+5
Land Use: (m²)	3.40E+5	3.40E+5	3.40E+5	2.27E+5	2.27E+5
Waste volume disposed: (m³)					
Regular:					
Chemical-stable	1.02E+4	1.02E+4	1.02E+4	1.02E+4	1.02E+4
Chemical-unstable	1.15E+5	1.15E+5	1.15E+5	1.15E+5	1.15E+5
No chemical-stable	2.23E+5	2.23E+5	2.23E+5	2.23E+5	2.23E+5
No chemical-unstable	5.34E+5	5.34E+5	5.34E+5	5.34E+5	5.34E+5
Total	8.82E+5	8.82E+5	8.82E+5	8.82E+5	8.82E+5

Table 5.10 (Continued)

Impacts	Case 4A	Case 4B	Case 4C	Case 4D	Case 4E
Layered:					
Chemical-stable	0	0	0	0	0
Chemical-unstable	1.87E+3	1.87E+3	1.87E+3	1.87E+3	1.87E+3
No chemical-stable	0	0	0	0	0
No chemical-unstable	9.59E+4	9.59E+4	9.59E+4	9.51E+4	9.51E+4
Total	9.77E+4	9.77E+4	9.77E+4	9.70E+4	9.70E+4
Hot waste facility:	0	0	0	0	0
Total disposed:	9.80E+5	9.80E+5	9.80E+5	9.79E+5	9.80E+5
Total volume not acceptable: (m^3)	1.94E+4	1.94E+4	1.94E+4	2.02E+4	1.94E+4

*Postoperational (closure and long-term care) costs are estimated to range from approximately $18.1 million to $38.2 million. In general, the higher end of the range would be associated with Case 4A and the lower end of range would be associated with Cases 4D and 4E. Total costs are therefore estimated to range as follows:

4A	4B	4C	4D	4E
2.19-2.39E+8	2.19-2.39E+8	2.28-2.48E+8	2.40-2.60E+8	2.43-2.63E+8

The additional operational steps for Cases 4B and 4C, which involve improved compaction for the former case and thicker disposal cell covers for the latter, are also not expected to result in significant additional exposures. For these cases, additional time would be spent on top of the disposal cells while installing the disposal cell covers. However, the disposal cell covers would provide considerable shielding (e.g., by a factor of about 1200 for every meter of soil) and any additional exposures would be small.

As shown for Cases 4D and 4E, however, a site operational procedure in which all waste containers are neatly stacked would be expected to increase occupational exposures by a factor of somewhat greater than 2. This may be an overestimate, however. At currently operating disposal facilities, a mixture of random and stacked disposal is generally used. High surface activity wastes and boxed low activity wastes are generally stacked (or otherwise emplaced in a neat manner using cranes or forklifts) while drummed low activity waste is generally disposed randomly. Additional stacking procedures would generally involve the lower activity waste streams. If waste segregation were not implemented, then the increased time spent in a high radiation environment would be expected to increase exposures. However, if the higher activity waste streams were disposed segregated from the low activity streams (most of the compressible wastes are trash and other low activity streams), then the radiation environment while stacking the lower activity wastes would probably be lower. The resulting exposures would also be lower.

As expected, operation of the hot waste facility (to dispose of the L-NFRCOMP stream) results in a somewhat increased volume of waste delivered to the disposal facility and total operational exposures would be somewhat higher than for Case 4D. However, total occupational exposures would be lower than if the wastes were disposed with the remainder of the waste streams.

Disposal costs illustrate the fact that increased costs for improved facility design and operations would be expected to reduce long-term care costs. Compared with Case 1-3 ($188 million), Cases 4A through 4D illustrate increasing costs as additional work is performed onsite. Additional costs for segregation (Case 4A) are associated with the assumed construction of a waste storage area, aquisition of an additional onsite transport vehicle and hiring of additional personnel. For Case 4B, additional costs involve aquisition and use of a vibratory compactor. Addition of an improved cover (Case 4C) is estimated to be reasonably expensive (an additional $9 million over 20 years). This was calculated from the assumption that a high grade of clayey soil had to be transported to the disposal facility from several miles distance. Of course, if such soil were available nearer to the facility (e.g., an onsite borrow area), the costs would be considerably reduced. Similarly, additional costs are associated with waste stacking (Case 4D). As can be seen, operation of a hot waste facility would be expensive--i.e., an additional $3 million to dispose of only 800 m^3 of waste.

Long-term care costs are difficult to estimate and have not been broken out in as detailed a manner as the costs associated with operational variables. It is difficult to precisely judge or to exactly quantify how much a given facility design and operation alternative would be expected to reduce long-term care costs. For this EIS, long-term care costs have been broken out into three levels: high, moderate, and low. Cases 4A through 4E have been judged to involve a range of costs from moderate to high--i.e., from $18.1 million to $38.2 million.

Case 4A is estimated to involve long-term care costs toward the higher end of the range, but would nonetheless be expected to be less than those for Case 1. This is because 75% of the waste disposed at the facility (7.47E+5 m^3) is in an unstable form, and segregation of unstable waste streams from stable waste streams would reduce overall long-term maintenance requirements. Instead of all disposal trenches undergoing severe subsidence, only about 75% would experience such subsidence. Cases 4D and 4E are estimated to involve long-term costs toward the lower end of the range. (The addition of a hot waste facility for small volumes of waste would be expected to have little to no effect on long-term care costs.) Cases 4B and 4C would involve long-term care costs between the two ends of the range.

Total costs (design and operational costs plus long-term care costs) are also shown in Table 5.10, along with unit costs (total costs divided by the total volume of waste disposed). These are also presented as a range in costs.

The remaining impact measures are total land use and energy use, where the energy value listed is the incremental sum of the total gallons of fuel for waste transport and disposal as well as for long-term care. For Cases 4A and 4B the total incremental energy use over 20 years is calculated to be 300,000 gallons. (Case 4B would actually be expected to involve slightly higher energy consumption than Case 4A, but the difference is too small to be illustrated.) For illustration purposes, incremental energy use for Cases 4A and 4B was calculated under an assumption of a high level of long-term care while incremental energy use for Cases 4C through 4E was calculated under an assumption of a moderate level of long-term care. As shown in Case 4C, although an additional operational step is involved (the thicker cap), the assumption of a moderate level of long-term care reduces the overall energy use to levels about the same as those for Case 1. In Case 4D and 4E, the waste containers are assumed to be stacked, which is an additional process step resulting in additional energy use. However, this is counteracted by the increase in disposal efficency, resulting in a decrease in land committed for waste disposal. Fewer disposal cells need to be constructed, backfilled, covered, compacted, and maintained. In addition, for Case 4D, less waste (by 800 m^3) is delivered to the disposal facility. Delivery of this waste to the facility and disposing of it in a hot waste facility (Case 4E) results in an increase in energy use over Case 4D.

The land use is 340,000 m^2 for Cases 4A-4C, and drops to 227,000 m^2 for Cases 4D and 4E. The reduction in land use is due to the assumption of waste stacking for the latter two cases. The disposal efficiency is assumed to be raised from 0.5 to 0.75. This may be difficult to achieve, however, in actual practice. Even if the waste is stacked, operational limitations may not reduce the interstitial void space between waste packages by very much.

5.2.4.3 Case 5 - Concrete Walled Trenches

This case is included to help assess the costs and radiological impacts of a potential disposal option in which site stability is achieved by engineering means. This case is summarized on Table 5.11. Appendix F investigates a number of methods by which subsidence and percolation of water into disposal cells may be reduced through engineering means. Other possible methods are investigated in Reference 5. These include such methods as grouting the disposed waste mass or placing the waste into engineered structures such as caissons or walled trenches. There may also be a number of other disposal designs which may be used.

Use of engineered methods at the disposal facility to achieve waste stability may, depending upon the particular disposal method utilized and the disposal site environment, involve a range of potential costs and radiological and other impacts. A rather "extreme" (expensive) method is illustrated in this example.

In this case, all wastes are assumed to be stacked into concrete walled trenches. In addition, unstable wastes and waste streams containing organic chemicals or complexing agents are disposed in segregated disposal cells. The spaces between the waste packages are grouted and a one-meter thick cap of concrete is poured over the waste, over which two meters of compacted clayey soil is emplaced and compacted. Grass is then planted.

Table 5.11 Summary of Cases 5 and 6

Case 5 - Cement Walled Trench
o Cement walled trench
o Waste spectrum 1
o Use of thicker, compacted clay cap
o Segregation of wastes containing chelates
o Segregation of compressible wastes
o Stacked disposal of waste
o Grouting emplaced between waste packages
o Cement walled trench used as an intruder barrier
Case 6 - Decontainerized Disposal of Compressible Wastes
o Regular SLB trench
o Waste spectrum 1
o Use of a thicker, compacted cap
o Segregation of wastes containing chelates
o Segregation of compressible wastes
o Random disposal except for low activity compressible wastes
o Decontainerized disposal of dry, low activity compressible wastes
o Use of a sand backfill
o Layering used as an intruder barrier

Ground-Water Impacts

Projected ground-water impacts are summarized in Table 5.12. As can be seen, all calculated exposures are lower than those estimated for the previous cases. The estimated organ doses, with the exception of thyroid and bone, are on the order of 10^{-3} mrem/yr at the site boundary well, are about 5 times higher at the intruder well, and drop by approximate orders of magnitude at both the population well and the surface water access location. The reason that boundary well whole body (and other organs) exposures are higher than those for the intruder well is that most of these exposures are still due to tritium, which is indicated by the observation that the maximum exposures occur at about 100 years following facility closure. (The actual maximum potential intruder well exposures are estimated to be about 1.3E-2 mrem, but occur prior (50 years) to the end of the active institutional control period.) For thyroid, there is less of a change. Exposures at the intruder and boundary wells are about 0.4 mrem/yr and those at the population well about 0.1 mrem/yr, while the surface water access is about an order of magnitude less. The reason that considerably less reduction in thyroid exposure is observed than for exposures to other organs is due to the assumption of a general deterioration in the disposal cells at the end of the active institutional control period. At a

Table 5.12 Estimated Radiological Ground-Water Impacts for Cases 5 and 6.

	(mrem/yr)						
Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(5)							
Intruder Well	8.096E-4 (100)	1.434E-3 (6,000)	8.096E-4 (100)	3.873E-1 (4,000)	8.096E-4 (100)	8.096E-4 (100)	8.096E-4 (100)
Boundary Well	4.179E-3 (70)	1.429E-3 (6,000)	4.179E-3 (70)	3.873E-1 (4,000)	4.179E-3 (70)	4.179E-3 (70)	4.179E-3 (70)
Population Well	2.229E-4 (10,000)	3.314E-4 (10,000)	1.163E-4 (10,000)	1.224E-1 (6,000)	1.976E-4 (10,000)	6.667E-5 (10,000)	1.491E-4 (10,000)
Surface Water	9.851E-6 (10,000)	1.363E-5 (10,000)	4.992E-6 (10,000)	5.577E-3 (10,000)	8.681E-6 (10,000)	2.732E-6 (10,000)	6.448E-6 (10,000)
(6)							
Intruder Well	2.487E-2 (6,000)	4.517E-2 (6,000)	2.156E-2 (100)	1.238E+1 (4,000)	2.235E-2 (6,000)	2.156E-2 (100)	2.156E-2 (100)
Boundary Well	1.113E-1 (70)	4.503E-2 (6,000)	1.113E-1 (70)	1.238E+1 (4,000)	1.113E-1 (70)	1.113E-1 (70)	1.113E-1 (70)
Population Well	7.096E-3 (10,000)	1.045E-2 (10,000)	3.690E-3 (10,000)	3.911E+0 (6,000)	6.287E-3 (10,000)	2.103E-3 (10,000)	4.739E-3 (10,000)
Surface Water	3.147E-4 (10,000)	4.347E-4 (10,000)	1.594E-4 (10,000)	1.783E-1 (10,000)	2.773E-4 (10,000)	8.713E-5 (10,000)	2.060E-4 (10,000)

time period equal to 100 years following license termination, approximately 10 percent of the disposal cells are assumed to be significantly disturbed by intrusion so that infiltration of rainwater into the disturbed disposal cells is increased from less than a millimeter per year to about 30 mm/year. The percolation over the remainder of the disposal area is raised to about 1.5 mm/yr. Since most of the boundary well exposures are due to migration of tritium, the hundred year time period of minimum infiltration allows considerable decay of the tritium inventory (by a factor of about 280) prior to initiation of the higher percolation rates. Since iodine-129 is so very long lived, the 100-year institutional control period has virtually no effect on the inventory in the disposal cells.

Other Impacts

Other impacts are listed in Table 5.13. It can be seen that the major differences from Cases 4A-4E are in occupational exposures at the disposal facility, costs, incremental energy use, and committed land.

Table 5.13 Other Impacts Associated with Cases 5 and 6

Impacts	Case 5	Case 6
Short-term population exposures: (man-mrem)		
Processing at waste generator	-	-
Processing at regional processing center	0	0
Waste transportation	5.10E+5	5.10E+5
Short-term occupational exposures: (man/mrem)		
Processing at waste generator	-	-
Processing at regional processing center	0	0
Waste transportation	5.82E+6	5.82E+6
Waste disposal	5.27E+6	1.05E+7
Waste generation and transport costs: ($)		
Processing at waste generator	-	-
Processing at regional processing center	0	0
Waste transportation	2.05E+8	2.05E+8
Disposal Costs: ($)		
Design and Operational	4.21E+8	2.56E+8
Postoperational	1.22E+7	1.81E+7
Total:	4.33E+8	2.74E+8
Unit ($/m^3)	442	280
Energy use: (gal)	+3.00E+5	-1.00E+5
Land use: (m^2)	5.33E+5	3.40E+5
Waste volume disposed: (m^3)		
Regular:		
Chemical-stable	1.02E+4	1.02E+4
Chemical-unstable	1.17E+5	1.15E+5
No chemical-stable	2.23E+5	2.23E+5
No chemical-unstable	6.30E+5	5.34E+5
Total	9.80E+5	8.82E+5
Layered:		
Chemical-stable	0	0
Chemical-unstable	0	1.87E+3
No chemical-stable	0	0
No chemical-unstable	0	9.59E+4
Total	0	9.77E+4
Hot Waste Facility	0	0
Total disposed:	9.80E+5	9.80E+5
Total volume not acceptable: (m^3)	1.94E+4	1.94E+4

Occupational exposures are seen to be in the range of 5.27 E+6 man-millirem, which is similar to the range of exposures calculated for Cases 4D and 4E, in which the waste is assumed to be stacked into the disposal cells. Waste is also assumed to be stacked for Case 5. These occupational exposures are more than twice those estimated for Case 1. Waste operations would all take place from the top of the disposal cells, and so the average distance between the workers and the disposed waste would be increased. On the other hand, waste disposal operations would take longer. In addition, use of walled trenches involves grouting of waste packages, which is an additional disposal step.

The most significant difference from earlier cases appears to be in the costs. Due to the expensive engineered disposal cells, facility design and operational costs for Case 4A are projected to climb to $421 million ($430/m^3, $12.20/ft^3), which is an increase by a factor of 2.25 from Case 1 and by about 2 from Case 4C. This may actually be a low estimate. Since this disposal technique has not been implemented on a full-scale basis at any disposal facilities, there would undoubtably be a number of logistical and practical details to work out. These could raise costs well above those estimated here. One of the practical difficulties, for example, would involve emplacement of all wastes from above the disposal cells using slings and hoists. This would be a straightforward task for liners and boxes, but would be considerably more difficult for drummed wastes. This is especially significant when one considers that the great majority of the LLW delivered to disposal facilities are delivered in 55-gallon drums.

On the other hand, the site stability resulting from the extensive engineering practices represented by use of the walled trench results in a considerable reduction in estimated long-term care costs. Long-term care costs are estimated at the lowest level ($12.2 million). Overall costs for Case 5 are estimated at $433 million, or an average of about $442 per m^3 of waste ($12.50/ft^3). As discussed above, these costs may actually be higher.

Another concern is equitability. Much of the waste is very low hazard material and often only suspected of being contaminated with radioactivity. This waste is quite often generated by small businesses or other concerns such as clinics, colleges, research facilities, and small manufacturers. In addition, a particular licensee may generate only small quantities of waste material per year. These factors increase the difficulty of the analysis and arriving at an equitable solution. On one hand, it is difficult to justify requiring disposal methods involving significantly increased costs to dispose of waste which may otherwise be of very low hazard. Such significantly increased costs would probably principally impact licensees such as small businesses or other concerns which may also only generate relatively small volumes of waste per licensee. On the other hand, disposal facility instability has been shown to a significant factor in long-term costs to a site owner.

Energy use is estimated to increase relative to Case 1--in this case by 200,000 gallons of equivalent fuel. In this calculation, the reduced energy use associated with long-term care is somewhat offset by the increased energy consumption associated with construction of the walled trenches. Due to greatly decreased efficiency of the walled trenches, land use is estimated to be approximately 1.57 times that for Case 1 and 2.35 times that for Case 4D.

5.2.4.4 Case 6 - Decontainerized Disposal of Compressible Waste

Case 6 is included to assess a potential alternative method of disposing of low activity compressible wastes. In this case, lower activity compressible wastes are assumed to be emptied out of containers into segregated disposal trenches, where the waste is periodically covered by a soil layer. Trenches for which this practice occurred would be operated in a similar manner as a sanitary landfill. Operations would be carried out under weather shielding (such as an air support building) to reduce wind scatter. This case is summarized on Table 5.11.

The rationale for considering this case is that with no rigid containers, there would be an overall reduction in void spaces within the disposal trenches containing the compressible wastes. There would be some initial slumping as the waste degrades, but after a few years, it could be assumed that an equilibrium condition could occur. Long-term maintenance requirements, relative to Case 1, would be reduced. This technique, however, has never been extensively used at a radioactive waste disposal facility.

Ground-Water Impacts

Maximum estimated ground-water radiological impacts for this case are summarized in Table 5.12, while other impacts are summarized in Table 5.13. Relative to Case 4C, ground-water impacts are seen to be the same at the four biota access locations. Maximum organ doses, except for thyroid, at the boundary well are in the range of 0.1 mrem, with exposures at the population well and the surface water access location in the range of 10^{-3} mrem, and 10^{-4} mrem, respectively. Thyroid exposures are considerably higher than the other organ doses at all access locations. As discussed previously, the maximum exposures at the intruder and boundary wells are mostly due to tritium and iodine.

Other Impacts

Also of interest are the other impacts shown in Table 5.13. Of concern is the greatly increased occupational exposures received during waste handling and disposal operations at the disposal facility. These are estimated to be approximately 4 times those for Case 1 and twice those for Case 4D. These exposures are uncertain, since this disposal technique has never previously been extensively used at any disposal facility, and could be higher.

Disposal facility design and operational costs are lower than those for Case 5, but are significantly higher than Cases 1 through 4E. Long-term care costs are especially difficult to estimate. The idea behind this disposal technique is that the reduction in void space and the increased rate of decomposition would result in decreased long-term maintenance requirements. However, given the somewhat speculative nature of this disposal technique, a moderate (rather than low) level of long-term care costs has been assumed. This results in a total disposal cost of $274 million, or $280/m³ ($7.93/ft³). This is less than the unit costs for Case 5, but greater than unit costs for Cases 1 through 4E.

Due to the reduced long-term care requirements, incremental energy use is reduced relative to Case 1 by about 100,000 gallons of equivalent fuel. Land use is similar to Cases 1 through 4C.

5.2.4.5 Case 7 - Use of Improved Waste Forms

Case 7 presents a significant change relative to the previous cases in that waste spectrum 2 is assumed rather than waste spectrum 1. In waste spectrum 2 the following is assumed:

- o All LWR concentrated liquids are evaporated to 50 weight percent solids.

- o All LWR process wastes, including liquids, ion exchange resins, filter media, and cartridge filters are solidified using improved solidification techniques (solidification scenario B). In this case, half the waste is assumed to be solidified in cement and the other half is assumed to be solidified in an improved polymer solidification agent.

- o Liquid waste streams from production of medical isotopes are assumed to be solidified in an improved polymer solidification agent (solidification scenario C).

- o All combustible waste streams are assumed to be compacted. All fuel cycle trash streams and half of the institutional and industrial waste streams are assumed to be compacted by the waste generator. The other half of the institutional and industrial combustible waste streams (I+COTRASH, N+SSTRASH, N+LOTRASH) are assumed to be compacted at a regional processing facility which is assumed to be colocated with the disposal facility. This results in a total volume of 1.025 E+5 m^3 of compressible material which is processed at the regional processing center to an approximate volume of 2.98 E+4 m^3 prior to disposal.

- o All higher activity waste streams are stabilized in a manner which is less likely to degrade and reduce in volume in a humid environment. These include the following waste streams: P-NCTRASH, B-NCTRASH, L-NFRCOMP, N-ISOPROD, AND N-HIGHACT. These waste streams are not in themselves unstable but are assumed to be packaged in waste spectrum 1 using compressible trash for shielding and/or containing large void spaces within the waste packages. There may be a number of ways in which these waste streams may be stabilized--e.g., for activated metals such as nonfuel reactor core components (L-NFRCOMP), void spaces within a waste package may be potentially filled with a nondegradable filter such as sand rather than compressible trash. The costs for such waste stabilization may vary depending upon the waste form and activity, but as an upper bound the costs of placing the waste streams into high integrity containers may be used. As discussed in Section 5.2.4.8, these costs are estimated as approximately \$450 per m^3 of waste.

In a number of ways waste spectrum 2 represents the direction in waste form and packaging toward which waste generators are heading. For examples, although there are no regional processing facilities currently operating, many licensees (particularly large licensees) have installed or are installing waste compacting equipment. In addition, license conditions at operating waste disposal facilities will shortly require that LWR ion exchange resins and filter media be either solidified or packaged in a high integrity container.

Due to the additional waste processing carried out by the waste generators and at the regional processing center, the total volume of waste is reduced in waste spectrum 2 from one million m^3 to 6.978E+5 m^3. In addition, the volume of unstable waste streams is reduced from 76% to 45% of the total waste spectrum. The activity in this waste spectrum, however, is assumed to remain the same.

Case 7 consists of 4 subcases in which successive disposal facility design and operational improvements are made. These 4 subcases are summarized briefly below and in more detail in Table 5.14:

- Case 7A. Similarly to Case 1A, waste streams are randomly disposed into disposal cells with no segregation of compressible waste streams or waste streams containing organic chemicals or chelating agents. A thin soil cover ("standard cap") is placed over the disposed waste and little compaction of the trench cover takes place.

- Case 7B. This case is similar to Case 4A in that easily compressible waste streams as well as waste streams containing significant quantities of chelating agents are assumed to be disposed in a segregated manner.

- Case 7C. This case is similar to Case 4B. In addition to segregation of the compressible waste streams and waste streams containing chelating agents, the disposal cell covers containing compressible waste streams are subjected to improved compaction techniques.

- Case 7D. This case is similar to Case 4C. In addition to waste segregation, thicker disposal cell covers composed of a high-grade clay soil are assumed to be emplaced over all the disposal cells, which are also subjected to improved compaction techniques.

Ground-Water Impacts

Maximum ground-water impacts at each of the four biota access locations are listed in Table 5.15. In general, the impacts calculated in Case 7A for the intruder and boundary wells are, except for thyroid exposures, similar to those calculated for Case 1A. Similarly, boundary well impacts for Cases 7B through 7D are, except for thyroid exposures, similar to those respectively calculated for Cases 4A through 4C. However, a more significant difference is observed for thyroid exposures at the intruder and boundary wells, as well as exposures to all organs at the population well and the surface water access location.

Table 5.14 Summary of Cases 7A-7D

Case 7A - Improved Waste Forms: No Segregation

- o Regular SLB trench
- o Waste spectrum 2
- o SLB with a standard cap
- o No segregation of wastes containing chelates
- o No segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 7B - Improved Waste Forms: Segregation

- o Regular SLB trench
- o Waste spectrum 2
- o SLB with a standard cap
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier.

Case 7C - Improved Waste Forms: Segregation Plus Compaction

- o Regular SLB trench
- o Waste spectrum 2
- o SLB with a standard cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Case 7D - Improved Waste Forms: Segregation, Compaction and Improved Covers

- o Regular SLB trench
- o Waste spectrum 2
- o SLB with a thicker clay cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste with a sand backfill
- o Layering used as an intruder barrier

Table 5.15 Estimated Radiological Impacts from Ground-Water Migration for Cases 7A through 7D

Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
	(mrem/yr)						
(7A)							
Intruder Well	3.042E+0 (100)	2.466E-1 (6,000)	3.042E+0 (100)	2.353E+1 (6,000)	3.042E+0 (100)	3.042E+0 (100)	3.042E+0 (100)
Boundary Well	1.570E+1 (70)	2.464E-1 (6,000)	1.570E+1 (70)	2.353E+1 (6,000)	1.570E+1 (70)	1.570E+1 (70)	1.570E+1 (70)
Population Well	2.044E-2 (10,000)	5.468E-2 (10,000)	1.397E-2 (10,000)	7.430E+0 (8,000)	1.889E-2 (10,000)	1.096E-2 (10,000)	1.594E-2 (10,000)
Surface Water	9.174E-4 (10,000)	2.425E-3 (10,000)	6.226E-4 (10,000)	3.387E-1 (10,000)	8.460E-4 (10,000)	4.855E-4 (10,000)	7.017E-4 (10,000)
(7B)							
Intruder Well	7.702E-1 (100)	2.158E-1 (6,000)	7.702E-1 (100)	2.500E+0 (6,000)	7.702E-1 (100)	7.702E-1 (100)	7.702E-1 (100)
Boundary Well	3.976E+0 (70)	2.156E-1 (6,000)	3.976E+0 (70)	3.976E+0 (70)	3.976E+0 (70)	3.976E+0 (70)	3.976E+0 (70)
Population Well	1.035E-2 (10,000)	4.680E-2 (10,000)	9.678E-3 (10,000)	7.858E+0 (8,000)	1.020E-2 (10,000)	9.362E-3 (10,000)	9.895E-3 (10,000)
Surface Water	4.598E-4 (10,000)	2.072E-3 (10,000)	4.290E-4 (10,000)	3.5E81-2 (8,000)	4.525E-4 (10,000	4.146E-4 (10,000)	4.386E-4 (10,000)
(7C)							
Intruder Well	7.645E-1 (100)	1.238E-1 (6,000)	7.645E-1 (100)	2.246E+0 (6,000)	7.645E-1 (100)	7.645E-1 (100)	7.645E-1 (100)
Boundary Well	3.947E+0 (70)	1.237E-1 (6,000)	3.947E+0 (70)	2.246E+0 (6,000)	3.947E+0 (70)	3.947E+0 (70)	3.947E+0 (70)
Population Well	6.279E-3 (10,000)	2.690E-2 (10,000)	5.668E-3 (10,000)	7.073E-1 (10,000)	6.139E-3 (10,000)	5.383E-3 (10,000)	5.868E-2 (10,000)
Surface Water	2.792E-4 (10,000)	1.191E-3 (10,000)	2.514E-4 (10,000)	3.224E-2 (10,000)	2.727E-4 (10,000)	2.384E-4 (10,000)	2.602E-4 (10,000)
(7D)							
Intruder Well	2.151E-2 (100)	3.352E-2 (6,000)	2.151E-2 (100)	5.277E-1 (6,000)	2.151E-2 (100)	2.151E-2 (100)	2.151E-2 (100)
Boundary Well	1.111E-1 (70)	3.339E-2 (6,000)	1.111E-1 (70)	5.277E-1 (6,000)	1.111E-1 (70)	1.111E-1 (70)	1.111E-1 (70)
Population Well	1.661E-3 (10,000)	7.249E-3 (10,000)	1.517E-3 (10,000)	1.661E-1 (10,000)	1.627E-3 (10,000)	1.450E-3 (10,000)	1.564E-3 (10,000)
Surface Water	6.848E-5 (10,000)	2.943E-4 (10,000)	6.194E-5 (10,000)	7.563E-3 (10,000)	6.695E-5 (10,000)	5.889E-5 (10,000)	6.402E-5 (10,000)

This pattern is basically due to the fact that under waste spectrum 2, while no change in waste form is assumed for the two low volume waste streams delivered to the facility containing very high concentrations of tritium (N-TRITIUM and N-TARGETS), all LWR process waste streams are placed into a stable waste form through solidification. In addition, a number of higher activity waste streams are packaged to achieve greater waste form stability over the long term.

For Case 7A, even though there is an overall improvement in waste form in waste spectrum 2, the disposal practice of mixing compressible waste streams with stable waste streams still results in trench subsidence problems and increased percolation into all of the disposal cells. This increased percolation is conservatively assumed to be the same as that for Case 1, although the additional compaction applied to compressible waste streams would actually be expected to reduce the rate of subsidence and thus reduce percolation. This effect is difficult to quantify but would be expected to be most significant over the short term. At any rate, tritium releases from the N-TRITIUM and N-TARGETS waste streams are essentially identical to those experienced in Case 1A, and almost identical whole body exposures at the boundary well result. After this pulse of tritium passes, however, the next highest calculated whole body exposures at the boundary well are about 0.8 mrem for Case 7A, while the next highest whole body boundary well exposures for Case 1A are about twice as high. Both of these maximums occur at about 6,000 years following license termination.

The reduced secondary maximums in Case 7A (relative to Case 1A) is principally due to the assumed use of less leachable waste forms for LWR process streams. This effect may be observed, for example, by comparing population well and surface water exposures in Cases 7A through 7D with the respective Cases 1A and 4A through 4C. This effect is most easily observed, however, by comparing thyroid exposures at all of the access locations. Comparing Cases 7A through 7D with Cases 1A and 4A through 4C, thyroid exposures are reduced by a factor of about 4 at the population well and the surface water access location. This is expected given the assumed reduction in leaching achieved from solidification of the LWR process waste streams.

<u>Other Impacts</u>

Other impacts are set out in Table 5.16. In it can be seen that potential population exposures from waste processing are still taken to be at negligible levels. This is because essentially all of the waste processing is done through compaction techniques, and potential airborne effluents from compaction are taken to be negligible compared to those potential exposures from incineration. Population exposures from waste transportation are slightly reduced--i.e., from 5.10 E+5 man-millirem to about 5.01 E+5 man-millirem over 20 years--which is a result of the reduced volume of waste that is delivered to the reference facility under waste spectrum 2.

Occupational exposures are all expected to increase with respect to Case 1. For example, total exposures for waste processors are estimated to rise by

Table 5.16 Other Impacts for Cases 7A Through 7D

Impacts	Case 7A	Case 7B	Case 7C	Case 7D
Short-term population exposures: (man-mrem)				
Processing at waste generator	-	-	-	-
Processing at regional processing center	0	0	0	0
Waste transportation	5.01E+5	5.01E+5	5.01E+5	5.01E+5
Short-term occupational exposures: (man-mrem)				
Processing at waste generator	+1.68E+6	+1.68E+6	+1.68E+6	+1.68E+6
Processing at regional processing center	1.25E+5	1.25E+5	1.25E+5	1.25E+5
Waste transportation	5.43E+6	5.43E+6	5.43E+6	5.43E+6
Waste disposal	2.34E+6	2.34E+6	2.34E+6	2.34E+6
Waste generation and transport costs: ($)				
Processing at waste generator	+3.38E+8	+3.38E+8	+3.38E+8	+3.38E+8
Processing at regional processing center	3.63E+7	3.63E+7	3.63E+7	3.63E+7
Waste transportation	1.85E+8	1.85E+8	1.85E+8	1.85E+8
Disposal Costs: ($)				
Design and operational	1.93E+8	1.92E+8	1.93E+8	1.99E+8
Long-term care	3.82E+7	1.81-3.82E+7	1.81E+7	1.22E-1.81E+7
Total:	2.31E+8	2.10-2.30E+8	2.11E+8	2.11-2.17E+8
Unit ($/m^3) (a)	341	310-340	311	311-320
Energy Use: (gal)	+8.00E+6	+8.00+6	+7.80E+6	+7.80E+6
Land Use: (m^2)	2.36E+5	2.36E+5	2.36E+5	2.36E+5
Waste volume disposed: (m^3)				
Regular:				
Chemical-stable	3.90E+4	4.00E+4	4.00E+4	4.00E+4
Chemical-unstable	7.40E+4	7.40E+4	7.40E+4	7.40E+4
No chemical-stable	1.32E+5	3.30E+5	3.30E+5	3.30E+5
No chemical-unstable	2.32E+5	2.32E+5	2.32E+5	2.32E+5

Table 5.16 (Continued)

Impacts	Case 7A	Case 7B	Case 7C	Case 7D
Layered:				
Chemical-stable	3.83E+3	2.87 E+3	2.87 E+3	2.87 E+3
Chemical-unstable	0	0	0	0
No chemical-stable	1.98E+5	0	0	0
No chemical-unstable	0	0	0	0
Total	2.02E+5	2.87E+3	2.87E+3	2.87E+3
Hot waste facility:	0	0	0	0
Total disposed:	6.78E+5	6.78E+5	6.78E+5	6.78E+5
Total volume not acceptable: (m^3)	1.94E+4	1.94E+4	1.94E+4	1.94E+4

*The indicated unit costs are obtained from dividing the total disposal costs by the volume of waste delivered to the disposal facility, which is about 680,000 m^3 for Case 7. If unit disposal costs were calculated using the "unprocessed" (waste spectrum 1) volumes disposed for Cases 1 through 6, unit costs would be as follows:

7A	7B	7C	7D
236	214-235	215	215-221

2.23E+6 man-millirem. Waste processing exposures at the regional processing center are calculated at 1.25E+5 man-millirem, which translates to 8.4 man-rem per year. Assuming two shifts, each composed of a two-man crew, this translates into an annual exposure of about 1.6 rems per man.

Waste transportation occupational exposures and waste disposal facility occupational exposures are generally reduced from the exposures set out in the previous Cases 1 through 6. The volume reduction tends to increase the concentration of the radionuclides in the resulting waste streams. However, the concentration of radionuclides is already so low in the compacted streams that the increased concentration is more than off-set by the reduced number of waste packages that must be handled.

Similarly, total population exposures from waste transportation are reduced with respect to Cases 1 through 6. This is again because of the reduced number of waste shipments for transfer of the same activity of waste to the disposal facility.

Of interest in this case is the relationship between processing costs, transportation costs, and disposal costs. As discussed by Tekenkron, (Ref. 6) the actual costs are quite variable and are a complicated function of disposal charges at the facility, transportation distances, the potential need to use shielded transport vehicles, the volume of waste processed, the costs of installing and maintaining waste processing equipment, and so forth. Additional expenditures would be, of course, required by a waste generator to install, use, and maintain compaction equipment. However, less storage space would be required by the waste generator, fewer shipping containers would be needed, and overall transportation costs would be expected to be reduced. This is borne out by Table 5.16. For the same activity in the waste spectrum, overall transportation costs over 20 years are estimated to be reduced by a factor of 1.13 over waste spectrum 1--e.g., from $205 million to $185 million.

For waste spectrum 2, total processing costs over 20 years are raised relative to waste spectrum 1 by $374.3 million. Of this additional $374.3 million, $36.3 million results from charges for processing by compaction of 1.025 E+5 m^3 of waste at the regional processing center. The compaction results in a total volume reduction of about 3.4 at an average cost of $354 per meter of unprocessed waste ($10.03/$ft^3$). Of the remaining additional $338 million expended by waste generators, approximately $40 million is due to processing 7 waste streams by compaction at the facilities at which the waste is generated. (These include the P-COTRASH, B-COTRASH, F-COTRASH, I-COTRASH, N-SSTRASH, N-LOTRASH, and I-LQSCNVL streams; which are reduced in total disposed volume relative to waste spectrum 1 from 3.8 E+5 m^3 to 2.2 E+5 m^3.) Of the remainder, approximately $257 million is expended in solidifying previously unstable LWR process waste streams, while approximately $41 million is conservatively assumed to be expended in stabilizing the higher activity waste streams.

Some care is required in interpreting these incremental waste processing costs. For example, costs for compaction of compressible wastes are already being borne by many licensees, generally as a means of reducing waste transport costs. The remaining expense is involved with stabilizing the higher activity waste streams. Much of the additional costs for waste stabilization involve costs for solidifying LWR ion exchange resins and filter media. Solidifying these waste streams is one way in which existing disposal license conditions may be met.

Some care is also required in interpreting the calculated disposal costs. As shown in Table 5.16, facility design and operation costs increase from $193 million to $199 million for Case 7A through 7D, reflecting the successive addition of facility design and operating options. Design and operating costs are reduced, however, for Cases 7A-7D compared with respective Cases 1A, 4A, 4B, and 4C. This is due to the reduced volume of waste delivered to the disposal facility.

Long-term care costs are difficult to estimate for Cases 7A through 7D, but would in general be considered to involve a reduced level of long-term care costs than those for the respective Cases 1A, 4A, 4B, and 4C. In Case 7A, for example, despite the additional processing costs and occupational exposures borne by waste generators in waste spectrum 2, the stable waste streams are still randomly mixed with unstable waste streams in the disposal cells. The potential for subsidence problems involving all waste disposal cells requires an assumption of a high level of long-term care costs. This assumption, however, is more conservative than the similar assumption for Cases 1-3 and 1A. The improved waste form provided by the compaction would resist degradation better than noncompacted waste. Potential voids would be slower to form and potential slumping problems reduced. If subsidence does occur, it would occur at a lower rate. This would reduce the labor required to maintain the facility and also reduce the percolation of water into the disposal cells containing compressible material, thus reducing potential ground-water migration from these disposal cells.

Long-term care costs for Cases 7B through 7D are estimated to be further reduced depending upon facility design and operating practices. In Case 7D, for example, a low to moderate range of long-term care costs is estimated. This can be compared with Case 4C, in which something greater than a moderate level of long-term care costs are estimated. In Case 4A, 76 percent of the disposed waste volume is in an unstable form while for Case 7D, this has been reduced to 45%. In addition, for Case 7D, waste streams having high concentrations of radionuclides have been stabilized to resist extreme volume change due to waste or waste package degradation. The inventory of radionuclides in the disposal cells containing unstable wastes has been considerably reduced, therefore reducing the potential migration impacts from these waste streams. This should lessen the concern over maintenance of these segregated trenches and help to reduce long-term costs.

Total disposal costs range from about $210 million to about $231 million over the 4 subcases. It is interesting to observe that the difference in the total costs over the 4 cases ($21 million) is much greater than the difference in design and operating costs. This is because the increase in design and operating costs is compensated by the reduction in long-term care costs.

As shown and as compared with Cases 1A and 4A through 4C, total costs have decreased, since the total waste volume delivered to the disposal facility has decreased, while unit costs have increased. This makes estimation of unit costs difficult as well as use of unit costs to compare alternatives. On one hand, the disposal facility would not fill up with waste as fast and so would be able to accept additional waste for disposal. However, the disposal facility may be restricted to accepting waste only from a particular region or group of states, in which case the operating life of the disposal facility would be extended. In addition, the lower volume of waste being accepted means less revenues received by the disposal facility operator. Capital and other overhead costs are not linearly dependent upon the volume of waste received, since many of the same activities would have to be performed at a disposal facility accepting a large volume of waste as one accepting a small volume of waste. Disposal facility operators would therefore tend to raise their prices to cover expenses.

At any rate, Table 5.16 illustrates two unit cost figures. One is calculated by dividing the total disposal costs by the volume of waste actually delivered to the disposal facility, which is about 680,000 m^3 for Case 7. The other unit cost is calculated by dividing the total disposal costs by the "unprocessed" (waste spectrum 1) volumes delivered to the disposal facility for Cases 1 through 6. From this, it would appear that use of total (20 year) disposal costs is a better unit to compare alternatives than unit costs.

Committed land use for the 4 subcases of Case 7 is 236,000 m^2. This is a significant drop from Cases 1 through 6 (e.g., 340,000 m^2 for most of the earlier cases) and reflects the lower volume of waste delivered to the disposal facility under waste spectrum 2.

Incremental energy use varies over a fairly narrow range, and reflects the opposing mechanisms of increased energy consumption for additional facility design and operation options and decreased energy consumption due to lower long-term maintenance requirements. In addition, increased energy consumption is associated with waste processing, while decreased energy consumption is associated with waste transportation and waste disposal operations. In general, however, and due to the additional waste processing, incremental energy consumption for Cases 7A through 7D are higher than the respective Cases 1A and 4A through 4C.

5.2.4.6 Case 8 - Use of Further Improved Waste Forms

This case is similar to Case 7D except that waste spectrum 3 is used instead of waste spectrum 2. Under waste spectrum 3, LWR process wastes are assumed to be solidified using further improved solidification agents (solidification scenario C), which is represented by a synthetic polymer having low leaching characteristics. LWR concentrated liquids are first evaporated to 50 weight percent solids. Extensive incineration of combustible material (except LWR process wastes) is performed. In this scenario, fuel cycle trash, LWR decontamination resins (L-DECONRS stream), trash from large institutions, and trash from large industrial firms are assumed to be incinerated at the point of generation. Trash streams from small institutional and industrial facilities (which include the I+COTRASH, N+SSTRASH, AND N+COTRASH waste streams) are assumed to be delivered to a regional processing center for incineration. This regional processing center is assumed to be colocated with the disposal facility. After waste incineration, the ashes are assumed to be solidified prior to disposal using a synthetic polymer (solidification scenario C).

Processing the waste in this manner results in a significant reduction in the amount of waste delivered to the disposal facility that is in an unstable form. That is, only the I+LQSCNVL, I+BIOWAST, N-LOWASTE, AND F-NCTRASH streams still exist in an unstable form, which only totals 2.079 E+4 m out of the 4.92 E+5 m^3 eventually disposed at the disposal facility (representing only 4% of the disposed volume). The design of the disposal facility is assumed to be similar to that for Case 7D, and is summarized in Table 5.17.

Waste segregation is performed at the disposal facility, and following random emplacement of the waste packages in the disposal cells, a thick clay cover is emplaced which is compacted using improved compaction techniques.

Table 5.17 Summary of Cases 8 and 9

<u>Case 8 - Further Improved Waste Forms</u>

- o Regular SLB trench
- o Waste spectrum 3
- o SLB with a thicker clay cap
- o Compaction using improved methods
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Random disposal of waste using a sand backfill
- o Layering used as an intruder barrier

<u>Case 9 - Improved Waste Forms and Cement Walled Trench</u>

- o Cement walled trench
- o Waste spectrum 3
- o Use of thicker, compacted cap
- o Segregation of wastes containing chelates
- o Segregation of compressible wastes
- o Stacked disposal of waste
- o Grouting emplaced between waste packages
- o Cement walled trench used as an intruder barrier

Ground-Water Impacts

Maximum ground-water impacts for this case for each of the four biota access locations are shown in Table 5.18. It is useful to compare these results with those for Case 7D. Compared with Case 7D, whole body intruder and boundary well exposures for Case 8 are only slightly reduced. This is because as in the case of waste spectra 1 and 2, no processing is performed on the N-TARGETS and N-TRITIUM waste streams. Releases of tritium from these waste streams are essentially at the same rates as in Case 7D. Comparing whole body exposures at the population well, however, reveals a reduction in exposures by a factor of between 5 and 6. Similarly, thyroid exposures for Case 8 have been reduced with respect to Case 7D. In Case 7D, maximum thyroid exposures at the intruder and boundary wells are about .5 millirem and occur at about 6,000 years following license termination. In Case 8, maximum intruder and boundary well thyroid exposures are about .22 millirem, a reduction by a factor of about 2.3.

Table 5.18 Summary of Ground-Water Impacts for Cases 8 and 9

	(mrem/yr)						
Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(8)							
Intruder Well	2.119E-2 (100)	4.629E-3 (6,000)	2.119E-2 (100)	2.216E-2 (6,000)	2.119E-2 (100)	2.2119E-2 (100)	2.119E-2 (100)
Boundary Well	1.094E-1 (70)	4.612E-3 (6,000)	1.094E-1 (70)	2.216E-1 (6,000)	1.094E-1 (70)	1.094E-1 (70)	1.094E-1 (70)
Population Well	2.913E-4 (10,000)	1.010E-3 (10,000)	2.306E-4 (10,000)	6.994E-2 (10,000)	2.786E-4 (10,000)	2.022E-4 (10,000)	2.540E-4 (10,000)
Surface Water	1.228E-5 (10,000)	4.109E-5 (10,000)	9.518E-6 (10,000)	3.187E-3 (10,000)	1.170E-5 (10,000)	8.223E-6 (10,000)	1.056E-5 (10,000)
(9)							
Intruder Well	8.060E-4 (100)	1.977E-4 (6,000)	8.060E-4 (100)	1.843E-2 (4,000)	8.060E-4 (100)	8.060E-4 (100)	8.060E-4 (100)
Boundary Well	4.161E-3 (70)	1.968E-4 (6,000)	4.161E+3 (70)	1.843E-2 (4,000)	4.161E-3 (70)	4.161E-3 (70)	4.161E-3 (70)
Population Well	1.617E-5 (10,000)	4.362E-5 (10,000)	1.111E-5 (10,000)	5.822E-3 (10,000)	1.512E-5 (10,000)	1.512E-6 (10,000)	8.742E-5 (10,000)
Surface Water	6.912E-7 (10,000)	1.762E-6 (10,000)	4.606E-7 (10,000)	2.653E-4 (10,000)	6.424E-7 (10,000)	3.527E-7 (10,000)	5.472E-7 (10,000)

Other Impacts

Other impacts are listed on Table 5.19. Of interest are short-term population exposures, short-term occupational exposures, and costs. Due to the incineration of the waste, airborne releases are assumed to occur in the environs of the waste generators and the regional processing center. Total airborne population exposures over 20 years due to processing by waste generators are 7.86E+6 man-millirem, which reduce to about 3.93E+5 man-millirem per year or about 19 man-millirem per m^3 of waste processed. Waste processing activities at the regional processing center are estimated to result in a total population dose of 3.74E+4 man-millirem over 20 years, or about 1,870 man-millirem per year (0.09 man-millirem per m^3 of processed waste disposed at the disposal facility). Given the 480,000 persons assumed to reside within 50 miles of the regional processing center, this averages to approximately 3.9 E-3 millirem per year per person within 50 miles.

Table 5.19 Other Impacts Associated with Cases 8 and 9

Impacts	Case 8	Case 9
Short-term population exposures: (man-mrem)		
Processing at waste generator	+7.86E+6	+7.86E+6
Processing at regional processing center	3.74E+4	3.74E+4
Waste transportation	5.04E+5	5.04E+5
Short-term occupational exposures: (man-mrem)		
Processing at waste generator	+1.18E+6	+1.18E+6
Processing at regional processing center	2.45E+4	2.45E+4
Waste transportation	5.40E+6	5.40E+6
Waste disposal	2.43E+6	4.86E+6
Waste generation and transport costs: ($)		
Processing at waste generator	+1.15E+9	+1.15E+9
Processing at regional processing center	9.50E+7	9.50E+7
Waste transportation	1.83E+8	1.83E+8
Disposal costs: ($)		
Design and Operations	1.93E+8	3.14E+8
Postoperational	1.22E+7	1.22E+7
Total:	2.05E+8	3.26E+8
Unit ($/m^3)*	417	663
Energy use: (gal)	+6.08E+7	+6.10E+7
Land use: (m^2)	1.71E+5	2.68E+5
Waste volume disposed: (m^3)		
Regular:		
Chemical-stable	8.68E+3	1.16E+4
Chemical-unstable	6.57E+4	6.57E+4
No chemical-stable	4.03E+5	4.03E+5
No chemical-unstable	1.15E+4	1.15E+4
Total	4.89E+5	4.92E+5
Layered:		
Chemical-stable	2.87E+3	0
Chemical-unstable	0	0
No chemical-stable	0	0
No chemical-unstable	0	0
Total	2.87E+3	0
Hot waste facility:	0	0
Total disposed:	4.92E+5	4.92E+5
Total volume not acceptable: (m^3)	1.13E+3	1.13E+3

*The indicated unit costs are obtained from dividing the total disposal costs by the volume of waste delivered to the disposal facility, which is about $490,000 m^3 for Cases 8 and 9. If unit disposal costs were calculated using the "unprocessed" (waste spectrum 1) volumes disposed for Cases 1 through 6, unit costs would be as follows:
Case 8: $209/m^3
Case 9: $333/m^3

Population exposures from transportation are seen to be less than those for Cases 1 through 6 (waste spectrum 1) and are in the same range as those of Cases 7A through 7D (waste spectrum 2). In Case 8, a decreased volume of waste must be shipped, which would tend to reduce exposures. This is balanced by the increased number of higher activity waste shipments that must be transported to the disposal facility.

Short-term occupational exposures are, in several cases, reduced from Cases 7A through 7D. For example, total occupational exposures from processing waste streams at waste generator facilities and at the regional processing center are reduced from Cases 7A-7D. This is because the occupational exposures are estimated based upon the time required to be spent in a radiation environment processing the waste. It requires less time to process a given volume of waste by incineration; hence, the estimated occupational exposures are reduced. Waste transportation occupation exposures are somewhat reduced with respect to Cases 7A-7D while, disposal facility occupational exposures are somewhat higher. This is because although there is a decrease in the volume of waste delivered to the disposal facility, this is balanced by an increase in the number of higher activity waste containers. In the calculations, less time is taken in proximity to the higher activity waste streams during waste loading and transportation than during waste unloading and disposal. This results in slightly lower transportation occupational exposures and slightly higher waste disposal facility occupational exposures.

The estimated total costs for waste processing, transport, and disposal are seen to be significantly higher than for the other cases. The most significant additional costs are, of course, incurred during waste processing. As can be seen, total additional processing costs at the waste generators are approximately 2.4 times those calculated for Cases 7A-7D. Processing charges at the regional processing center run at about $927/m^3 ($26.25/ft^3), and are raised over Cases 7A-7D by a factor of about 2.6. Processing costs in this range again brings up the question of equitability. Incinerating the waste and solidifying the remaining ash does place the waste into a much more stable form. For some facilities which generate very large volumes of combustible waste, incineration may be an effective means of reducing transportation and disposal costs. It would be a difficult requirement to implement generally, however, as a means of stabilizing otherwise low hazard waste. Such extensive processing activities could not be implemented within a short time frame and would probably be a financial burden to most licensees--particularly small licensees such as hospitals and research laboratories.

Transport costs are about a factor of 1.14 less than those for Cases 1 through 6 and slightly lower than those for Cases 7A-7D. This is because on one hand, less shipments are required for transport of a given activity of waste to the disposal facility. On the other hand, more use must be made of expensive shielded transport vehicles and casks.

Total disposal costs relative to Cases 7A-7D are reduced. Unit costs, however, are raised. Because only about 4% of the waste is still in an unstable form and improved disposal cell covers and compaction techniques are implemented, the disposal facility is assumed to be placed in a stable condition.

Also predictably, land use is seen to drop to 1.65E+5 m^2, which is a reduction by a factor of 2 with respect to Case 1 and by a factor of 1.4 with respect to Case 7. Incremental fuel use is seen to be significantly greater than the preceding cases, which is basically caused by the increased use fuel to incinerate the waste.

5.2.4.7 Case 9 - Walled Trenches and Further Improved Waste Forms

This case investigates a rather extreme example of near-surface radioactive waste disposal. As in Case 8, waste spectrum 3 is assumed to be applied. However, in Case 9 as in Case 5, all wastes are assumed to be disposed into concrete walled trenches. The waste streams are segregated, stacked within the disposal cells, and grouted in place. A summary of this case is included as Table 5.17.

Ground-Water Impacts

Potential ground-water impacts are the lowest of the cases considered. Maximum exposures at the intruder and boundary wells are in the range of 10^{-4} to 10^{-3} mrem for most organs. Maximum thyroid exposures at the intruder and boundary wells are approximately .02 mrem at 4,000 years following license termination. The difference between the thyroid exposures and exposures to all other organs is more striking for the population well and surface water exposures. For the population well, for example, organ doses except thyroid are in the range of 10^{-7} to 10^{-5} millirem while thyroid exposures are in the range of 10^{-4} to 10^{-3} millirem.

Other Impacts

Other impacts are presented in Table 5.19. Since the same waste spectra is used, most of the short-term radiological impacts are the same as those for Case 8. However, occupational exposures are estimated to significantly rise due to the use of the concrete walled trench. Additional time must be spent in close proximity to the waste containers while emplacing the (stacked) waste and while grouting the waste mass.

Total disposal costs are estimated to be significantly ($123 million over 20 years) higher than for Case 8. Due to the use of the walled trench, design and operating costs are about $316 million, while again a low level of long term care and long term care costs are estimated ($12.2 million). Incremental energy use is some what higher than that for Case 8. Land use is also higher--e.g., by about a factor of about 1.6.

5.2.4.8 Case 10 - High Integrity Containers

The preceding case studies investigated a number of ways to improve the stability of the disposal facility. As discussed, improved facility stability can be achieved by segregating unstable low activity material from the higher activity waste material and by stabilizing the higher activity waste material. This stability can be achieved through disposal facility design and operating practices (e.g., emplacing the waste into engineered disposal cells such as walled trenches or caissons) or through a stable waste form (e.g., solidifying dispersible high activity waste streams such as ion exchange resins or filter media, incinerating and solidifying compressible trash). These alternatives serve to maintain the integrity of the disposal cell covers and thus reduce the percolation of water through the disposal cell covers and subsequent contact with the waste. In the case of solidification, an additional improvement is gained in that the potential for radionuclides leaching from the solidified waste is assumed to be reduced.

Another viable alternative would be to place the high activity waste into a high integrity container (HIC). In this case, the container would be constructed in a much more robust manner than the containers generally used to transport wastes to disposal facilities. The HIC would be designed to resist crushing from static loads and corrosion from the contained wastes as well as the surrounding soils. The HIC could therefore provide the needed support to the disposal cell covers to minimize subsidence and to reduce infiltration. In addition, since the wastes would be contained inside the HIC, leaching of radionuclides from the HIC would be negligible as long as the HIC retained its integrity. (Note that corrosion through or damage of a portion of an HIC, which could compromise its ability to withstand leaching, would not be expected to generally reduce its ability to provide structural support for the disposal cell covers.) Another advantage to use of an HIC is that, compared with solidification, it may be easier to assure quality control over the final waste product.

To date, HICs have not been generally used to package wastes for disposal, although within the last few years there has been considerable interest in this concept--chiefly, as an alternative to solidification of ion exchange resins and filter media. Use of HICs is allowed by the South Carolina Department of Health and Environmental Control at the Barnwell, S.C. disposal facility. Performance criteria for HICs for the Barnwell facility have been drafted by South Carolina and these are listed in Table 5.20.

One HIC design which has been approved by the South Carolina Department of Health and Environmental Control is currently being marketed. The HIC is constructed principally of polyethylene and is currently available in designs ranging from 2.4 m^3 (84 ft^3) to 9 m^3 (316 ft^3). Special designs are advertised as being available upon request.

Other groups, including the Department of Energy, are also investigating HIC designs. Use of high integrity containers is planned for some waste streams generated from the decontamination of Three Mile Island Unit Two.

As a corollary to potential use of high integrity containers, there is also some interest is using polyethylene or other types of plastic 55-gallon drums for packaging lower activity wastes such as trash. Polyethylene drums are available, for example, which have been certified by DOT for use in transporting certain types of nonradioactive hazardous wastes such as oxidizers or corrosive solids. These are apparently available at approximately the same (or possibly reduced) price as standard steel 55-gallon drums. Compared to steel 55-gallon

Table 5.20 State of South Carolina Criteria for High Integrity Containers

The general criteria for high integrity containers to be used for high concentration waste forms is as follows:

1. The container must be capable of maintaining its contents until the radionuclides have decayed, approximately 300 years, since two of the major isotopes of concern in this respect are strontium-90 and cesium-137 with half-lives of 28 and 30 years, respectively.

2. The structural characteristics of the container with its contents must be adequate to withstand all the pressure and stresses it will encounter during all handling, lifting, loading, offloading, backfilling, and burial.

3. The container must not be susceptible to chemical, galvanic or other reactions from its contents or from the burial environment.

4. The container must not deteriorate when subjected to the elevated temperatures of the waste streams themselves, from processing materials inside the container, or during storage, transportation and burial.

5. The container must not be degraded or its characteristics diminished by radiation emitted from its contents, the burial trench or the sun during storage.

6. All lids, caps, fittings and closures must be of equivalent materials and construction to meet all of the above requirements and must be completely sealed to prevent any loss of the container contents.

Source: Chem-Nuclear Systems, Inc., "High Integrity Container Systems," November 17, 1980 (Ref. 7).

drums, which is the most common type of waste container used in the nuclear industry, a polyethylene or other type of plastic drum would be expected to degrade much slower after disposal, provided that the drum is designed to be compatible with the waste form and the disposal environment. The radionuclide containment capability would therefore be expected to be greater than a typical steel 55-gallon drum. More importantly, reduced container degradation would result in reduced compression of disposal cell contents, thus reducing subsidence and infiltration of water.

The following 3 cases examine use of high integrity containers from 2 viewpoints: (1) reduction of migration of tritium, and (2) as an alternative to solidification as a means of providing waste stability. For the former case, recall that solidifying LWR process waste streams served to reduce exposures at the population well and surface water access location, but had less of an effect at the intruder well and the boundary well (e.g., see the results for Cases 7D and 8). These exposures were primarily due to migration of tritium. As discussed previously, two small volume industrial (nonfuel cycle) waste streams contain large quantities of tritium and yet were subjected to no improvements in waste form in waste spectra 2 and 3.

The 3 cases considered are the following:

- Case 10A. In this case, the design of the disposal facility is assumed to be the same as Cases 4C and 7D. Compressible wastes are segregated, the wastes are backfilled with sand, and a thick cover of clayey soil is emplaced which is compacted using improved compaction methods. Waste spectrum 2 is assumed. High integrity containers assumed to be effective for 100 years are applied to 2 industrial waste streams which contain large quantities of tritium: N-TRITIUM and N-TARGETS. The combined 20-year volume of these streams is only 1332 m^3, but the total tritium content is 2.27 million curies.

- Case 10B. This case is similar to Case 10A, except that waste spectrum 2 is assumed. Otherwise, the disposal facility is assumed to be the same design as Case 7D, and the 100-year HICs are applied to the same two low volume waste streams: N-TRITIUM and N-TARGETS.

- Case 10C. This case investigates the possible use of HICs for packaging of a number of waste streams. In this case, the same facility disposal design as the above two cases is assumed. Waste Spectrum 1 is also assumed. However, HICs assumed to be effective for 300 years are used for all LWR process waste streams except solidified liquids, as well as the 2 streams discussed above containing high quantities of tritium. In addition, other high activity waste streams which were packaged in a stable manner for waste spectrum 2 are also stabilized for this case. These include the following streams: P-NCTRASH, B-NCTRASH, L-NFRCOMP, N-ISOPROD, and N-HIGHACT.

Ground-Water Impacts

Estimated ground-water impacts from these two cases are presented in Table 5.21. These results may be compared with Cases 4C and 7D.

As can be seen by comparing Table 5.9 with Table 5.21, use of the HIC to package the two small volume tritium streams results for Case 10A in a reduction in boundary well impacts by a factor of about 4.5 to all organs except bone and thyroid. In the calculations, exposures to neither the bone nor the thyroid are limited by the migration of tritium. Hence, use of HICs has little effect on boundary well exposures to bone and essentially no effect on exposures to thyroid. Since tritium is a short half-lived isotope, use of the HICs on the two streams in question also has little effect on the exposures at the population well and the surface water.

Table 5.21 Estimated Radiological Impacts from Ground-Water Migration for High Integrity Container Cases 10A-10C

(mrem/yr)							
Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(10A)							
Intruder Well	2.487E-2 (6,000)	4.517E-2 (6,000)	1.410E-2 (6,000)	1.238E+1 (4,000)	2.235E-2 (6,000)	9.074E-3 (6,000)	1.751E-2 (6,000)
Boundary Well	2.485E-2 (6,000)	4.503E-2 (6,000)	1.407E-2 (6,000)	1.238E+1 (4,000)	2.232E-2 (6,000)	9.045E-3 (6,000)	1.749E-2 (6,000)
Population Well	7.096E-3 (10,000)	1.045E-2 (10,000)	3.690E-3 (10,000)	3.911E+0 (6,000)	6.287E-3 (10,000)	2.103E-3 (10,000)	4.739E-3 (10,000)
Surface Water	3.147E-4 (10,000)	4.347E-4 (10,000)	1.594E-4 (10,000)	1.783E-1 (10,000)	2.773E-4 (10,000)	8.713E-5 (10,000)	2.060E-4 (10,000)
(10B)							
Intruder Well	7.371E-3 (6,000)	3.352E-2 (6,000)	6.917E-3 (6,000)	5.277E-1 (6,000)	7.268E-3 (6,000)	6.706E-3 (6,000)	7.070E-3 (6,000)
Boundary Well	7.346E-3 (6,000)	3.339E-2 (6,000)	6.892E-3 (6,000)	5.277E-1 (6,000)	7.243E-3 (6,000)	6.680E-3 (6,000)	7.044E-3 (6,000)
Population Well	1.661E-3 (10,000)	7.249E-3 (10,000)	1.517E-3 (10,000)	1.661E-1 (6,000)	1.627E-3 (10,000)	1.450E-3 (10,000)	1.564E-3 (10,000)
Surface Water	6.848E-4 (10,000)	2.943E-4 (10,000)	6.194E-5 (10,000)	7.563E-3 (10,000)	6.695E-5 (10,000)	5.889E-5 (10,000)	6.402E-5 (10,000)
(10C)							
Intruder Well	1.352E-2 (6,000)	3.755E-2 (6,000)	9.431E-3 (6,000)	4.702E+0 (6,000)	1.256E-2 (6,000)	7.524E-3 (6,000)	1.072E-2 (6,000)
Boundary Well	1.347E-2 (6,000)	3.730E-2 (6,000)	9.382E-3 (6,000)	4.702E+0 (6,000)	1.251E-2 (6,000)	7.475E-3 (6,000)	1.068E-2 (6,000)
Population Well	3.568E-3 (10,000)	8.341E-3 (10,000)	2.275E-3 (10,000)	1.485E+0 (6,000)	3.260E-3 (10,000)	1.673E-3 (10,000)	2.672E-3 (10,000)
Surface Water	1.548E-4 (10,000)	3.417E-4 (10,000)	9.585E-5 (10,000)	6.769E-2 (10,000)	1.406E-4 (10,000)	6.843E-5 (10,000)	1.135E-4 (10,000)

Impacts for Case 10B may be compared with those for Case 7D in Table 5.15. Compared with Case 7D, boundary well exposures to organs other than bone and thyroid are also reduced by a factor of about 15. In Case 7D, several high activity waste streams are stabilized by solidification or improved packaging. Migration from these high activity streams (relative to Case 4C) is reduced, leaving the tritium. Use of 100-year HICs on the two high tritium content streams thus produces somewhat more dramatic results.

The reduction in impacts due to tritium migration calculated in Cases 10A and 10B is interesting, but should be viewed with caution. There has been little or no testing of tritium containment using high integrity containers. In addition, the usefullness of the HIC to contain tritium would be a strong function of the form of the tritium. A high integrity container would be ineffectual, for example, in containing tritium as a gas. Still, use of high integrity containers or other types of high integrity packaging is an interesting concept for further work.

Impacts shown for Case 10C fall between those calculated for Case 10A and 10B. Compared to Case 10A, impacts for most organs are reduced by about a factor of somewhat less than 2. However, compared to Case 10B, impacts for most organs except thyroid are raised by about a factor of 2. Thyroid exposures compared with Case 10B are raised by about a factor of about 9.

Other Impacts

Other impacts for the three cases are shown in Table 5.22. As shown, short-term population exposures and short-term occupational exposures are not expected to vary significantly from those respectively for Case 4C (Table 5.9) and Case 7D (Table 5.15). The same types of activities would be required to handle, process, transport, and dispose of the waste; one is merely substituting one container design for another. Similarly, as there would be no increase in waste volume from using HICs, transportation costs would not change from the previous cases.

Waste processing costs would increase somewhat. Since use of HICs is a relatively new concept and have only recently been commercially available, there is less data to compare costs with other waste stabilization techniques. However, using solidification of LWR ion-exchange resins and filter media as an example, an HIC would be more expensive than merely dewatering the resins and filter media but less expensive than solidification. No new equipment would need to be installed at the waste generator's facility.

Costs for use of an HIC would depend upon a number of variables such as the size of the container or the chemical content of the waste. In addition, use of an HIC may be sold as part of other services such as waste pick-up, transport, and disposal. One estimate is that an HIC would cost approximately 75% to 85% higher than a similarly sized carbon steel liner (Ref. 8). This figure has been used to estimate costs for use of an HIC as about $450 per cubic meter of packaged waste.

As shown, use of the HICs in the first two cases results in only a small increase in the total processing costs relative to the previous Cases 4C and 7D. Compared with Case 4C, higher costs are calculated for Case 10C since the volume of waste placed into HICs is significantly increased. However, total costs are significantly reduced from the processing costs calculated in Case 7D for waste solidification. Previously calculated additional solidification costs for LWR process wastes (waste spectrum 2) ran at about $257 million, while total costs for use of an HIC on 5 of the 7 process waste streams reduced costs to about $31 million. As in waste spectrum 2, stabilizing the other higher activity waste streams is conservatively estimated to cost an additional $41 million over 20 years of waste disposal.

Table 5.22 Other Impacts Associated with High Integrity Container Cases 10A-10C

Impacts	Case 10A	Case 10B	Case 10C
Short-term population exposures: (man-mrem)			
Processing at waste generator	0	0	0
Processing at regional processing center	0	0	0
Waste transportation	5.10E+5	5.01E+5	5.10E+5
Short-term occupational exposures: (man-mrem)			
Processing at waste generator	-	+1.68E+6	-
Processing at regional processing center	0	1.25 E+5	0
Waste transportation	5.82 E+6	5.43 E+6	5.82 E+6
Waste disposal	2.46 E+6	2.34 E+6	2.46 E+6
Waste generation and transport costs: ($)			
Processing at waste generator	+5.99E+5	+3.38E+8	+7.19E+7
Processing at regional processing center	0	3.63E+7	0
Waste transportation	2.05E+8	1.85E+8	2.05E+8
Disposal costs: ($)			
Design and operational:	2.10E+8	1.99E+8	2.08E+8
Postoperational:	1.81-3.82E+7	1.22-1.81E+7	1.22-1.81E+7
Total	2.28-2.48E+8	2.11-2.17E+8	2.20-2.26E+8
Unit ($/m^3)	233-253	311-320	224-231
Energy Use: (gal)	+4.00E+5	+7.80E+6	+1.00E+5
Land use: (m^2)	3.40E+5	2.36E+5	3.40E+5
Waste volume disposed: (m^3)			
Regular:			
Chemical-stable	1.02E+4	4.00E+4	1.02E+4
Chemical-unstable	1.15E+5	7.40E+4	1.15E+5
No chemical-stable	2.23E+5	3.30E+5	3.96E+5
No chemical-unstable	5.34E+5	2.32E+5	4.57E+5
Total	8.82E+5	6.76E+5	9.78E+5
Layered:			
Chemical-stable	0	2.87E+3	1.87E+3
Chemical-unstable	1.87E+3	0	0
No chemical-stable	0	0	0
No chemical-unstable	9.59E+4	2.87E+3	1.87E+3
Total	9.77E+4		
Hot waste facility:	0	0	0
Total disposed:	9.80E+5	6.78E+5	9.80E+5
Total volume not acceptable: (m^3)	1.94E+4	1.94E+4	1.94E+4

Little or no change to previously calculated disposal costs, total incremental energy use, or land use is estimated for Cases 10A and 10B.

In Case 10C, some minor changes to disposal costs compared with Case 4C are observed, due to the increased volume of stable waste streams delivered to the disposal facility.

5.2.5 Intruder Impacts Associated With the Case Study

This section addresses the following potential impacts from human intrusion into the disposal waste:

- Potential exposures to inadvertent intruders associated with the design options in the case study.
- Potential offsite exposures to individuals and populations from water and air transport to the environs of wastes exposed by the intruder.

These potential exposures are considered here for calculational convenience. In Chapter 4, the potential exposures associated with implementation of a performance objective for potential inadvertent intrusion were considered. In preceding sections of this chapter, costs and radiological impacts associated with minimizing long-term ground-water releases, while at the same time minimizing long-term social commitment were considered.

Table 5.23 presents potential intruder exposures, calculated at 100 years and 500 years following facility closure, for each of the design cases considered in the previous sections. Potential exposures to whole body and bone are shown, and the results are the volume-weighted average of the potential hazard of all waste streams delivered to the disposal facility. Table 5-23 also presents offsite exposures to bone and whole body from water and dispersion of waste streams exposed by a potential inadvertent intruder. Impacts are calculated at 100 years following termination of the facility license. Airborne releases are in man-millirem and are calculated for the total population within a 50-mile radius of the disposal facility. For this calculation, the expected population is assumed to be double that assumed for the reference facility while it is operating. Waterborne releases are calculated for an individual, and are estimated based upon the assumed erosion of the wastes into a nearby stream, where the water is used by the individual for consumption, watering crops, etc.

5.2.6 Summary of Observations and Conclusions Regarding the Case Study

The preceeding subsection of Section 5.2 presented 20 cases, including the base (no-action) cases, which were used to analyze costs and impacts associated with alternative methods to minimize contact of water with disposed waste and to reduce potential long-term maintenance costs. These methods included disposal facility design and operation alternatives, waste form and packaging alternatives, or combinations thereof.

Table 5.23 Waste Volume Averaged Individual and Population Intruder Impacts For the Ground-Water Migration Case Study

	Cases									
	1*	2	3	4A	4B	4C	4D	4E	5	6
Direct intruder impacts										
Body (mrem)										
o 100 C**	8.048E+1	8.048E+1	8.048E+1	3.085E+1	3.085E+1	3.085E+1	4.639E+1	4.636E+1	2.172E+0	3.085E+1
A	8.470E+1	8.470E+1	8.470E+1	2.499E+1	2.499E+1	2.499E+1	3.748E+1	3.745E+1	0	2.499E+1
o 500 C	1.526E+0	1.526E+0	1.526E+0	1.526E+0	1.526E+0	1.991E+0	1.991E+0	1.991E+0	2.290E-1	1.526E+0
A	1.756E+0	1.756E+0	1.756E+0	1.756E+0	1.756E+0	2.270E+0	2.270E+0	2.270E+0	2.634E-1	1.756E+0
Bone (mrem)										
o 100 C	8.780E+1	8.780E+1	8.780E+1	3.621E+1	3.621E+1	3.621E+1	5.412E+1	5.409E+1	2.185E+0	3.621E+1
A	9.080E+1	9.080E+1	9.080E+1	2.974E+1	2.974E+1	2.974E+1	4.461E+1	4.457E+1	0	2.974E+1
o 500 C	4.522E+0	4.522E+0	4.522E+0	4.522E+0	4.522E+0	4.522E+0	6.470E+0	6.470E+0	6.784E-1	4.522E+0
A	3.462E+0	3.462E+0	3.462E+0	3.462E+0	3.462E+0	3.462E+0	4.635E+0	4.635E+0	5.192E-1	3.462E+0
Offsite releases from intrusion:										
Airborne impacts (man-mrem)										
o Body	1.880E+3	1.880E+3	1.880E+3	1.387E+3	1.387E+3	1.387E+3	2.083E+3	2.081E+3	1.041+1	1.387E+3
o Bone	3.404E+4	3.404E+4	3.404E+4	2.152E+4	2.152E+4	2.152E+4	3.771E+4	3.768E+4	1.885E+2	2.152E+4
Waterborne impacts (mrem)										
o Body	4.121E-3	4.121E-3	4.121E-3	2.090E-3	2.090E-3	2.090E-3	3.131E-3	3.129E-3	3.599E-4	2.090E-3
o Bone	1.077E-2	1.077E-2	1.077E-2	7.300E-3	7.300E-3	7.300E-3	1.075E-2	1.074E-1	8.613E-4	7.300E-3

*Impacts for Case 1A are the same as those for Case 1.

**As shown, impacts are calculated at 100 and 500 years following license termination. The letter "C" signifies the intruder construction scenario, "A" the intruder-agriculture scenario.

Table 5.23 (continued)

	Cases								
	7A	7B	7C	7D	8	9	10A	10B	10C
Direct intruder impacts									
Body (mrem)									
o 100 C	4.093E+1	3.259E+1	3.259E+1	3.259E+1	2.825E+1	4.451E+0	3.085E+1	3.259E+1	2.517E+1
A	4.590E+1	2.151E+1	2.151E+1	2.151E+1	2.109E+0	0	2.499E+1	2.151E+1	1.507E+1
o 500 C	1.925E+0	1.925E+0	1.925E+0	1.925E+0	3.078E+0	4.617E-1	1.526E+0	1.925E+0	1.526E+0
A	2.205E+0	2.205E+0	2.205E+0	2.205E+0	3.475E+0	5.212E-1	1.756E+0	2.205E+0	1.756E+0
Bone (mrem)									
o 100 C	4.567E+1	3.360E+1	3.360E+1	3.360E+1	2.902E+1	4.477E+0	2.421E+1	3.360E+1	2.639E+1
A	5.500E+1	2.606E+1	2.606E+1	2.606E+1	4.526E+0	0	2.974E+1	2.606E+1	1.881E+1
o 500 C	6.251E+0	6.251E+0	6.251E+0	6.251E+0	9.041E+0	1.356E+0	4.522E+0	6.251E+0	4.522E+0
A	4.668E+0	4.668E+0	4.668E+0	4.668E+0	6.598E+0	9.898E-1	3.462E+0	4.668E+0	3.462E+0
Offsite releases from intrusion									
Airborne impacts (man-mrem)									
o Body	2.222E+3	1.194E+3	1.194E+3	1.194E+3	1.125E+3	6.564E+0	1.387E+3	1.194E+3	1.369E+3
o Bone	4.023E+4	2.161E+4	2.161E+4	2.161E+4	2.037E+4	1.188E+2	2.512E+4	2.161E+4	2.478E+4
Waterborne impacts (mrem)									
o Body	3.104E-3	1.848E-3	1.848E-3	1.848E-3	9.794E-4	7.165E-6	2.090E-3	1.848E-3	1.408E-3
o Body	1.088E-2	5.512E-3	5.512E-3	5.512E-3	2.867E-3	2.189E-5	7.300E-3	5.512E-3	4.338E-3

The costs and impacts of these 20 cases are summarized in Table 5.24. In this table, maximum ground-water impacts over 10,000 years following disposal facility closure are presented as potential exposures to whole body and thyroid from consumption and use of water obtained from wells assumed to be located down gradient of the disposed waste. One well, which is assumed to be located at the boundary of the disposal facility and 30 m downgradient of the edge of the disposed waste, is assumed to be used by individuals. The other well, which is assumed to be located 500 meters down gradient of the disposal facility boundary and halfway between the disposal facility and a hydrologic boundary (a stream), is assumed to supply the water needs for a small population.

Also shown in the table are total increment short-term population impacts in man-mrem, total incremental population impacts in man-mrem, and total incremental costs. Incremental impacts and costs are presented as additional costs and impacts to those associated with Case 1. Included in each incremental total impact measure are the following:

Total Short-Term Population Exposures	Total Short-Term Occupational Exposures	Total Costs
Processing at waste generator	Processing at waste generator	Processing at waste generator
Processing at regional center	Processing at regional center	Processing at regional center
Waste transport	Waste transport	Waste transport
	Waste disposal	Waste disposal: o design and op. o postoperational

Based upon the analyses in the preceding sections and as summarized in Table 5.24, a number of observations and conclusions can be reached:

1. Disposal facility stability is of great importance in reducing ground-water migration and minimizing costs for long-term care. Disposal facility stability is also believed to be an important prerequisite for other operational improvements such as improved disposal cell covers to minimize percolation of water and to reduce ground-water impacts to levels as low as reasonably achievable. In the EIS, the principal improved disposal cell cover examined was a thick compacted clay cap. There may be a number of other techniques such as polymer membranes or soil cement which may also be used. However, as long as the stability of the disposal cell cannot be reasonably assured, then the slumping and collapse associated with an unstable disposal cell will reduce (if not completely negate) the effectiveness of an improved cover.

Table 5.24 Summary of Costs and Impacts for Cases 1 through 10C

	Cases									
	1	2	3	1A	4A	4B	4C	4D	4E	5
Groundwater impacts: (mrem/yr)										
Boundary Well										
o Whole body	157	145	26.4	15.7	3.99	3.95	0.11	0.074	0.074	0.004
o Thyroid	846	268	825	84.6	80.5	45.4	12.4	8.3	8.3	0.39
Population Well										
o Whole body	0.44	0.055	1.03	0.048	0.046	0.026	0.007	0.005	0.005	0.0002
o Thyroid	267	26.8	651	26.7	25.4	14.4	3.91	2.61	2.61	0.12
Total incremental short-term population impacts: (man-mrem) ($\times 10^5$)	-	-	-	-	-	-	-	-0.16	-	-
Total incremental short-term occupational impacts: (man-mrem) ($\times 10^6$)	-	-	-	-	-	-	-	+2.72	+2.73	+2.81
Total incremental costs: ($) ($\times 10^8$)	-	-0.03	+0.12	+.07	(-.07)-.13	(-.07)-.13	(-.02)-.22	.1-.3	.17-.37	2.07

Table 5.24 (Continued)

	Cases									
	6	7A	7B	7C	7D	8	9	10A	10B	10C
Groundwater impacts: (mrem/yr)										
Boundary Well										
o Whole body	.11	15.7	3.98	3.95	.11	.11	0.004	.025	.0073	.013
o Thyroid	12.4	23.5	3.98	2.25	.53	.22	0.018	12.4	.53	4.70
Population Well										
o Whole body	.0071	.02	.01	.0063	.0017	.0003	1.6E-5	.0071	.0017	.0036
o Thyroid	3.91	7.4	.79	.71	.17	.07	0.0006	3.91	.17	1.49
Total incremental short-term population impacts: (man-mrem) (x 10^5)	-	-0.09	-0.09	-0.09	-0.09	+7.89	+7.89	-	-0.09	-
Total incremental short-term occupational impacts: (man-mrem) (x 10^6)	+8.04	+1.30	+1.30	+1.30	+1.30	+.76	+3.18	-	+1.30	-
Total incremental costs: ($) (x 10^8)	.48	+3.59	3.38-3.58	+3.39	3.39-3.45	+12.02	+13.23	.026-.23	3.39-3.45	.66-.72

From the analysis, it appears that there are a number of ways in which greater disposal facility can be achieved, ranging from disposal facility design and operating practices, to waste form and packaging practices, to combinations thereof. The major ways investigated are summarized below.

2. One general way by which disposal facility stability can be achieved is to improve the form of the waste through waste processing and packaging techniques. For example, waste spectrum 1 is assumed for Cases 1 through 6 and in this waste spectrum, 75% of the waste is in an unstable, degradable form. Waste spectrum 2 is assumed for Cases 7A through 7D, for which 45% of the waste is in an unstable form. Finally, waste spectrum 3 is assumed for Cases 8 and 9, for which only 4% of the waste is in an unstable form. In each waste spectrum, additional stability is achieved at additional processing and additional expense--particularly for waste spectrum 3. The following is an illustrative summary of the additional (from waste spectrum 1) processing and transport costs and impacts associated with waste spectra 2 and 3. The numbers in the parentheses illustrate additional costs and impacts if no regional processing were performed.

	Spectra	
Impact measures	2	3
Population exposures	-0.09	78.9
($x10^5$ man-mrem)	(-0.09)	(78.5)
Occupation exposures	1.42	0.79
($x10^6$ man-mrem)	(1.29)	(0.76)
Costs	3.13	11.8
($x10^8$ $)	(2.77)	(10.85)

Of interest is the comparison of population exposures and costs for waste spectra 2 and 3. In waste spectrum 2, the reduced population exposures compared with waste spectrum 1 are due to the reduced volume of waste transported. In waste spectrum 3, however, the greatly increased population exposures is due to the extensive incineration of combustible waste. Most of the (significant) cost differential between waste spectrum 2 and waste spectrum 3 is also due to waste incineration. Much of this additional cost would be borne by small scale enterprises such as hospitals and research laboratories.

Another important consideration is the timing for implementation of the waste spectra. For example, except for the assumed processing by compaction at a regional processing center, waste spectrum 2 represents in many respects the current trends of the waste generating industry. Many, if not most, of the larger waste generators have installed compactors and are compacting compressible waste streams as a means of reducing disposal costs. License conditions implemented by state action at all three operating disposal facilities will shortly require that resins, filter media, and other types of high activity wet wastes be either solidified or packaged in high integrity containers. Therefore, the degree of waste stability illustrated by waste spectrum 2 (all higher activity wastes are placed into a stable form) can be quickly achieved.

In contrast, the degree of stability achieved through waste spectrum 3 (96% of the waste volume is processed or packaged into a stable waste form) could not be implemented in a short time frame. Incinerators would have to be constructed and licensed, which would take several years. This option would also result in significantly larger short-term population exposures than waste spectrum 2. As shown, the great majority (99+%) of these additional exposures would result from processing the waste at the waste generator's facilities rather than at the regional processing center. The option is also expensive. For example, processing the waste at the regional processing center is estimated to cost about $927 per m^3 of waste delivered to the center ($26.25/$ft^3$). This represents a significant level of expense for the smaller waste generators such as hospitals, clinics, and research laboratories.

3. In waste spectra 2 and 3, stability for most waste streams was achieved through solidification of the waste. As a source term for the groundwater analyses, the leaching of unsolidified waste forms was first estimated through use of radionuclide concentrations of leachate samples acquired from the Maxey Flats disposal facility. It is believed that the use of this leachate is reasonable yet conservative. Then, fractional multipliers for solidified waste were estimated based upon limited leaching data obtained from studies by Brookhaven National Laboratory (BNL). It is recognized that the estimated fractional multipliers are only crude approximates, but were included in the analysis to assess the likely upper bound of what could be achieved through reducing the potential for leaching of radioactive waste forms.

   Three cases examined for which the potential for improved overall leaching characteristics may be compared include Cases 4C (waste spectrum 1), 7D (waste spectrum 2), and 8 (waste spectrum 3). These three cases all assumed the same disposal facility design and operating practices but assumed different waste spectra. The calculated results for each of these three cases are as follows:

	Case 4C	Case 7D	Case 8
	Spectrum 1	Spectrum 2	Spectrum 3
Boundary Well			
o Whole body	.1	.1	.1
o Thyroid	12.4	0.5	0.2
Population Well			
o Whole body	.007	.002	.0003
o Thyroid	3.9	0.2	.07

The calculated impacts indicate that improved lower leaching waste forms do reduce ground-water migration. However, it is difficult to determine the actual degree of credit that should be given to improved leaching characteristics of waste forms in determining ground-water impacts. For example, most of the work on leaching of solidified waste has been performed on small samples under laboratory conditions. Little or no laboratory data is available for many of the radionuclides which appear to be of most concern from a ground-water migration standpoint (e.g., H-3, Tc-99, I-129). Given the current state of knowledge, it appears that the principal credit that can be assumed from waste solidification is that it tends to place the waste into a more stable form. (Solidified forms having lower relative leaching characteristics also appear to have better structural strengths.)

4. The analyses in Cases 10A-10C indicate that a high integrity container can be a useful alternative to solidification. It has potential for successful containment of waste and preclusion of migration until the shorter-lived radionuclides have decayed. Of both shorter- and longer-term interest, it appears to offer a less expensive (than waste solidification) means of waste stabilization.

5. One operational technique that the analysis indicates as being very useful in achieving greater disposal facility stability is by segregating unstable, compressible waste streams from stable waste streams. In the analysis, waste segregation was estimated to cost an approximate additional $6/m³ ($0.17/ft³) in disposal facility design and operating costs. However, the practice enables an overall reduction in long-term maintenance costs. If waste segregation is not implemented, then all of the disposal cells would contain significant quantities of compressible wastes and increased maintenance activities would be therefore expected for each disposal cell. If waste segregation is implemented, then the increased maintenance activities would only be required for the waste cells containing the compressible waste. This amounts to 75% of the waste for waste spectrum 1, 45% of the waste for waste spectrum 2, and only 4% of the waste for waste spectrum 3.

The effects of segregation on reducing ground-water impacts is illustrated to a certain extent by comparing ground-water impacts associated with Case 1A with those of Case 4A, and comparing those associated with Case 7A with those of Case 7B. That is:

	Case (mrem/yr)			
Organ	1A	4A	7A	7B
Boundary Well				
o Whole body	15.7	3.99	15.7	3.98
o Thyroid	84.6	80.5	23.5	3.98
Population Well				
o Whole body	.048	.046	.02	0.01
o Thyroid	26.7	25.4	7.43	.79

As shown by comparing the difference between Case 1A and Case 4A (waste spectrum 1) with Case 7A and 7B (waste spectrum 2), not segregating the waste streams reduces the effectiveness of the improved stability and leaching characteristics associated with spectrum 2. Segregation is also seen to be an important prerequisite for other operational improvements such as improved disposal cell covers and improved compaction. As long as the stability of a disposal cell cannot be assured, then the slumping and collapse associated with an unstable disposal cell will reduce (if not negate) the effectiveness of an improved cover.

6. Decontainerized disposal, which was analyzed as Case 6, does not appear to be a viable disposal technique for generalized applications. Decontainerized disposal would appear to be useful for occasional disposal of such wastes as low activity bulk solids, contaminated building rubble, or occasional large pieces of machinery, provided that the disposal operations were carried out in an operationally safe manner and that disposal cell voids were eliminated during disposal. As a general practice extended to all compressible wastes, however, the potential improvement in ground-water impacts does not appear to be particularly impressive. In addition, significantly higher occupational exposures are expected to occur. Finally, it is an option which would require significant changes in current disposal operations and would not appear to be achievable within a short time frame.

7. Stacked disposal of waste rather than random disposal of waste is estimated to reduce ground-water impacts by a factor of approximately 1.5. This is illustrated by comparing the results of Case 4C with Case 4D. At currently operating disposal facilities, wastes are

generally disposed by a mixture of techniques, depending upon the ease in which the particular waste container can be handled and the level of activity within the container. If all wastes were required to be stacked on disposal, then occupational impacts at the disposal facility would be expected to rise significantly. Based upon this, it does not appear that the potential reduction in ground-water migration due to stacking is sufficient by itself to require its use generally. However and as discussed below, waste stacking would appear to have a more favorable cost-benefit evaluation when it is carried out as part of other operational techniques such as grouting or placement of wastes into engineered structures.

8. Cases 5 and 9 investigate options in which more extensive operational measures are implemented at the disposal facility to achieve disposal facility stability. In Case 5, for example, waste spectrum 1 is assumed and the wastes are stacked and grouted into cement walled trenches. Case 9 is similar to Case 5 except that waste spectrum 3 is assumed.

   Both of these cases result in rather significant reductions in potential ground-water migration as well as postoperational costs at significantly additional disposal facility design and operation costs as well as additional occupational exposures. For example, compared with Case 1, Case 5 is estimated to result in an additional 2.73 E+6 man-mrem in occupational exposures (over 20 years) at the disposal facility. This is principally due to stacking the waste into the disposal cells. Total costs (due to disposal only) are estimated to run at an additional $207 million over 20 years. In comparison to Case 8, Case 9 is estimated to involve an additional 2.47E+6 in occupational exposures and an additional $121 million in total disposal costs.

9. Most of the alternative disposal facility design and operating practices examined ways in which the disposal facility can be stabilized so that influx of water into disposal cells is minimized. Case 1A investigated an example in which the disposal cells are backfilled with sand prior to installation of the cap. This is done to help fill voids between waste packages to increase the vertical speed of water percolating into the disposal cells, thus reducing the time of contact with the disposed waste. In Case 1A, this was estimated to reduce potential migration (compared with Case 1) by a factor of about 10. It is recognized that there is uncertainty regarding the precise effectiveness of techniques such as the sand backfill. Nonetheless, it appears to be a useful and inexpensive technique for reducing potential impacts.

10. In a recent amendment to 10 CFR Part 20, NRC exempted liquid scintillation vials and animal carcasses containing tritium or carbon-14 in quantities greater than .05 μCi/gm from disposal as radioactive waste (Ref. 9). That is, these waste streams do not have to be transferred

to a licensed disposal facility for disposal but may be disposed through other means. Depending upon the nature of the nonradioactive material of which the waste is composed, this may include disposal through ordinary refuse channels or disposal into a nonradioactive hazardous waste disposal facility.

It is currently difficult to gauge with accuracy the effect of this amendment to Part 20 on the volumes of wastes delivered to disposal facilities. The reduction in the volume of liquid scintillation waste and biowaste delivered to disposal facilities will undoubtably be significant. This amendment, however, will not completely eliminate the volumes of these wastes delivered to disposal facilities. For example:

- Wastes containing concentrations of tritium or carbon-14 exceeding 0.05 μCi/gm would still require disposal into a licensed radioactive waste disposal facility.
- Wastes containing radionuclides other than tritium or carbon-14 would still require disposal into a licensed radioactive waste disposal facility.
- There may be local pressure or requirements against a particular waste generator disposing of tritium and carbon-14 waste by other means than as radioactive waste.

Given this current uncertainty, the amendment has conservatively not been considered when calculating migrational impacts from waste disposal. That is, liquid scintillation and biowaste volumes have been assumed to be delivered to the reference disposal facility and disposed. The effect of this conservatism can be illustrated in the following two cases, in which ground-water calculations for Cases 1 and 7D are recalculated with the biowaste and liquid scintillation waste streams deleted from the disposed waste inventory.

Results are presented in Table 5.25, and may be compared with the results for Case 1 presented in Table 5.3 and with the results for Case 7D presented in Table 5.15. As shown, ground-water impacts in Table 5.25 are only slightly reduced over the respective impacts in Tables 5.3 and 5.15. For Case 1, for example, whole body exposures at the population well are reduced from 0.44 mrem to 0.43 mrem. Similarly, exposures to the GI tract at the population well are reduced for Case 7D from .0016 mrem to .0013 mrem. Apparently, inclusion of the liquid scintillation and biological waste streams in the calculations has had little effect upon the results.

11. In the analysis, the most significant short-term impacts appear to be due to tritium while the most significant long-term impacts appear to be due to iodine-129. Releases of both of these isotopes can be minimized by stable site conditions. Much of the tritium waste appears to be concentrated in a few low volume waste streams and for these streams it appears that further reductions in migration can possibly

Table 5.25 Summary Radiological Impacts for Cases 1 and 7D Without Liquid Scintillation Vial Waste and Biowaste

	(mrem/yr)						
Cases	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(1)							
Intruder	3.041E+1	2.710E+0	3.041E+1	8.461E+2	3.041E+1	3.041E+1	3.041E+1
Well	(100)	(6,000)	(100)	(4,000)	(100)	(100)	(100)
Boundary	1.570E+2	2.709E+0	1.570E+2	8.461E+2	1.570E+2	1.570E+2	1.570E+2
Well	(70)	(6,000)	(70)	(4,000)	(70)	(70)	(70)
Population	4.338E-1	5.519E-1	2.009E-1	2.673E+2	3.791E-1	1.111E-1	2.743E-1
Well	(6,000)	(8,000)	(6,000)	(4,000)	(6,000)	(8,000)	(8,000)
Surface	1.769E-2	2.348E-1	7.077E-3	1.218E+1	1.515E-2	4.700E-3	2.577E-1
Water	(8,000)	10,000)	(8,000)	(4,000)	(8,000)	(10,000)	(8,000)
(7D)							
Intruder	2.116E-2	2.812E-2	2.116E-2	5.266E-1	2.116E-2	2.116E-2	2.116E-2
Well	(100)	(6,000)	(100)	(6,000)	(100)	(100)	(100)
Boundary	1.107E-1	2.812E-2	1.107E-1	5.266E-1	1.107E-1	1.107E-1	1.107E-1
Well	(70)	(6,000)	(70)	(6,000)	(70)	(70)	(70)
Population	1.433E-3	6.110E-3	1.289E-3	1.659E-1	1.400E-3	1.223E-3	1.336E-3
Well	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)
Surface	5.924E-5	2.482E-4	5.270E-5	7.554E-3	5.771E-5	4.965E-5	5.478E-5
Water	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)	(10,000)

be achieved through use of improved containers (e.g., see high integrity container Cases 10A and 10B). For example, a container which provided 100 years of containment would reduce the contained activity through radioactive decay by a factor of 280.

Unlike tritium, however, iodine-129 has a very long half-life and the use of improved containers would provide only a negligible amount of additional decay. The principal gain is through improved disposal cell stability which allows reduced percolation of water through disposal cell covers. Another control mechanism would be to limit the disposal site inventory of iodine-129 and other long-lived mobile isotopes such as Tc-99 or C-14. Such an inventory limit could not be generic, however, but would have to be established on a site-specific basis.

Another important consideration which would tend to reduce the impact of migration of iodine-129 is dilution by natural iodine. Environmental concentrations of I-129 with respect to nautural iodine (I-127) has been the subject of several studies (Refs. 10, 11). One study indicates that around existing nuclear facilities, the atom-ratio of

I-129 to that of I-127 measured in biota ranges up to 3.9×10^{-5} in thyroid tissues of animals other than bovine (deer around the Hanford Reservation), and up to 1.7×10^{-6} in bovine thyroid tissues (around Northeastern Oregon) (Ref. 10). In another study, bovine thyroid tissues have been observed to have an I-129/I-127 atom ratio of 4.5×10^{-7} around the Savannah River plant (Ref. 11). It has also been estimated that the I-129/I-127 ratio may possibly be as high as 0.0035 in the waste/soil mixture in a disposal site (Ref. 12). This calculation assumes the disposal of waste from 25 reactors and an average I-127 concentration in soil of 1 ppm. The authors of Reference 12 further calculate that if this atom ratio is below 0.02 it would not be possible to exceed the existing dose guidelines for thyroid exposures.

It is also possible that the iodine-129 in waste may be diluted through natural iodine produced as a daughter of Te-127 (which is a fission product). Additional dilution could be potentially inexpensively achieved by merely adding stable iodine to waste streams containing iodine-129.

Experimental environmental data and calculations such as the above have led some investigators in the past to utilize the total body dose to humans as a better indicator of the exposure due to I-129 than the thyroid dose (Ref. 13). This selection results in a significant difference in exposures since the ingestion dose conversion factors for thyroid are about 800 times that of total body. A correction to the calculated I-129 thyroid exposures to account for dilution with natural iodine has not been made in this EIS, however. The concentration of natural iodine in soil varies from place to place and there has as yet been no confirmatory measurements of iodine-127 concentrations in the soils and underlying aquifers at any of the existing disposal facilities. Neither have any measurements or calculations been as yet performed regarding the I-129/I-127 ratio in waste streams such as BWR ion exchange resins.

5.3 DEVELOPMENT OF A PERFORMANCE OBJECTIVE FOR MIGRATION AND LONG-TERM STABILITY

Based upon the above case study and the observations and conclusions that can be derived from the case study, a performance objective for ground-water migration and disposal facility stability may be developed. It is necessary to consider these two concepts simultaneously, since disposal facility stability directly affects the potential for ground-water migration and the ease in which potential impacts may be predicted. Disposal facility stability also affects the viability of engineering measures which can be implemented to reduce percolation into disposal cells. (The specific measure examined numerically in this EIS was use of a thick compacted clay cap. However, this does not preclude use of other possible techniques such as polyester membranes or soil sealants). Unless disposal cell slumping and subsidence can be controlled to low levels, the effectiveness of such engineering measures can be seriously reduced.

Perhaps most importantly, disposal facility stability and the corresponding potential for ground-water migration directly affect the level of long-term care and maintenance by the site owner. Past experience with LLW disposal clearly indicates that one of the most important objectives of LLW disposal should be that the disposal facility is stabilized so that little or no maintenance is required by the site owner. NRC staff believes that the alternative of not considering this as a performance objective is clearly not acceptable.

Given this as an objective, then the question that arises is how it may be implemented, or how much should be spent now to reduce costs later. Much of the difficulty is caused by the form of the waste. Most of the waste sent to LLW disposal facilities consists of very low activity material such as trash which is frequently easily degradable and compressible, and packaged in containers such as large wooden boxes and 55-gallon mild steel drums. Large void spaces can also exist within waste packages and the disposal cell after waste disposal. As the waste material degrades and compresses, a process which is accelerated by contact by water, additional voids are produced. This leads to settlement of the disposal cell contents, followed by subsidence or slumping of the disposal cell cover. This increases the percolation of water into disposal cells, accelerating the cycle. This slumping and subsidence is frequently quite sudden.

A number of alternatives for increasing disposal cell stability were considered in the preceding case study. These alternatives included minor to moderate changes in disposal facility design and operating practices (e.g., waste segregation, improved compaction), more extensive changes to disposal facility design and operating practices (e.g., grouting, concrete walled trenches, decontainerized disposal), and improved waste forms and packaging. The analysis is complicated by the paradox that most of the waste streams that contribute the most to site instability are the same waste streams that contain the least activity. Much of this low activity waste is only suspected of being contaminated and/or is generated by small waste generators such as hospitals and research laboratories. These factors increase the difficulty of arriving at a cost-effective solution to the problem of disposal facility instability. That is, it is difficult to justify requiring large additional expenditures to dispose of otherwise low hazard material.

One alternative would be to incinerate and solidify all combustible waste streams. In general, although NRC staff believes that waste incineration may be a cost-effective solution for some waste generators, it would cause economic hardships if required generally, particularly to small waste generators such as hospitals and research laboratories. In addition, it is not a solution that could be generally instituted on a reasonable time basis. Other alternatives such as extensive engineered disposal techniques (e.g., grouted or concrete walled trenches, decontainerized disposal) also appeared to have a number of drawbacks for general application. These drawbacks included significant additional disposal costs and significantly increased occupational exposures at the disposal facility.

The most reasonable alternatives considered--those which could be implemented with reasonable costs and within a reasonable time frame--involved stabilization of higher activity waste streams coupled with segregated disposal of lower activity unstable waste streams. Such stabilization of the higher activity streams could be accomplished by either stabilizing the waste form (e.g., through solidification), stabilizing the waste package (e.g, through use of high integrity containers), or by disposal facility design (e.g., by placing the waste into a structure which supports barriers to moisture). Once the disposal cells are stabilized, then improved barriers to moisture may be potentially emplaced, further reducing exposures to levels as low as reasonably achievable.

This means that there still may be some long-term maintenance required for the segregated lower activity waste disposal cells. However, this maintenance can be reduced through such measures as

- improved fill
- improved disposal cell covers, including improved compaction
- compaction of compressible wastes
- increased attention paid to minimizing voids in the waste containers
- use of longer lasting waste containers (e.g., polyethylene containers)

Through such measures, it is possible that the level of maintenance required for the low activity disposal cells can be reduced to very low levels. Increased consideration of disposal facility stability may be required at disposal facilities having very impermeable soils and located in a humid environment.

Given this overall objective--the need for disposal facility stability--numerical limits for migration are needed for purposes of evaluating the safety of existing facilities and licensing new facilities.

An important factor that must be considered is that the development of limits for ground-water releases are part of EPA's establishment of generally applicable environmental standards for LLW disposal. At this time the EPA standards have not been developed and will not be developed prior to issuance of the Part 61 regulation. After review of the responsibilities, authorities, and relationship of NRC and EPA with respect to standards and regulations, it appears that there are two alternatives for further development of the Part 61 regulation:

- Delay development of the numerical limits until EPA establishes generally applicable environmental standards for ground-water migration;
- Establish interim performance objectives, and modify the interim objectives when the EPA standard is available.

The first alternative appears to be unacceptable as EPA does not intend to develop standards for LLW disposal within a short time frame. Development of a ground-water migration performance objective--and the Part 61 regulation--would be delayed for an indefinite period until the EPA standard is developed and finalized. This delay could potentially last several years.

The second alternative is judged to be the preferred alternative and has been followed by NRC. Under this alternative, there is a potential for possible future changes to the performance objective when the EPA standard is implemented. These potential changes can be minimized, however, through NRC and EPA cooperation in the development of the Part 61 regulation and the EPA standard. In addition, draft EPA standards should be well under development and potentially issued by the time NRC is ready to issue final regulations. Setting out a range of alternatives and analyzing them as part of the LLW EIS would provide a basis for early discussion and focus of attention on what should be in the standard.

As for the case of the intruder analyses, a number of existing standards may be analyzed for consideration as a performance objective for ground-water migration. Except for the potential use of onsite water from a well excavated by an inadvertent intruder, potential exposures could be expected to be chronic and possibly be experienced by populations. Examples of existing standards which can be considered include the following:

- o limits established in 10 CFR Part 20 for permissible levels of radiation in unrestricted areas (500 mrem/year to the whole body)
- o 40 CFR 190
- o 10 CFR 50, Appendix I
- o 40 CFR 141

These standards, all which have been discussed in Chapter 4 as part of setting a performance objective for the potential inadvertent intrusion, represent a range of potential exposures of from 4 mrem/year to 500 mrem to the whole body. (Also see Appendix N for a more complete discussion of these existing standards.)

An important consideration is the point where the ground-water standard is to be applied, and the size of the population which could be potentially exposed. That is, in general, higher exposures could be allowed for a few individuals than to groups of people or populations.

It is believed that a general limit of 500 mrem/yr to the whole body (10 CFR 20.105 and 20.106) would not be generally applicable for the case of ground-water migration from disposal facility. In any case, EPA limits established in 40 CFR 190 have been adopted into 10 CFR 20 as a limit for releases from the nuclear fuel cycle. Most of the activity delivered to the disposal facility will probably be generated from nuclear fuel cycle activities, and such a limit would appear to be transferable to potential releases from a disposal facility. NRC currently uses a limit in this range for analyzing disposal facilities for long-term safety. As stated in the Low Level Waste Licensing Branch Technical Position on Burial Ground Closure and Stabilization (Appendix I), NRC staff currently use a criteria of small fractions of the limits in 10 CFR 20 at the site boundary and the requirements in the National Primary Drinking Water Standards (40 CFR 141) at the nearest source of drinking water. The limits in 10 CFR 50, Appendix I are in the same general range.

As part of development of this standard, a number of discussions have been held with EPA staff regarding the NRC development of an interim standard and the ultimate development of the EPA general standard. During these discussions, EPA staff indicated that they expected that their general environmental release standard would probably end up in the same approximate range--i.e., from about one to 25 mrem/year at the site boundary.

At any case, Cases 1 through 10C can be used to analyze alternative limits for a ground-water migration performance objective. Table 4.24 summarizes these cases, and also provides a summary of whole body and thyroid exposures at the site boundary as well as at a well assumed to be approximately 500 meters downstream and used by a small population. In the case study, exposures to seven organs were calculated. Thyroid exposures were included in Table 5.24 since these exposures were generally the largest of the organs considered. Of the remaining 6 organs, whole body was selected for Table 5.24 as representative. In the case study, exposures to most of the other organs were comparable or somewhat lower. Exposures to bone, however, were generally somewhat higher (e.g., by a factor of about 2-3). Whole body was included, however, as it better illustrated the effects of tritium migration, which dominates the boundary well exposures but has little or no effect at the population well.

Exposures received at the nearest downstream drinking water supply to the disposal facility would appear to be more controlling than those at the boundary of the disposal facility. In the calculations, exposures at the intruder and boundary wells are principally characterized by a contribution from long-lived mobile isotopes such as Tc-99 and I-129 as well as a contribution by shorter-lived isotopes such as tritium or Sr-90. By the time the contamination reaches the population well, however, the shorter-lived isotopes have mostly decayed away and exposures are dominated by the longer-lived isotopes.

This is indicated by comparing the results of the case study in Table 5.24.

In Table 5.24, the largest (limiting) exposures are to the thyroid, which is principally due to iodine-129, a mobile long-lived (15.9 million years) isotope. According to the assumptions for this EIS, this isotope is only slightly retarded by ion exchange and therefore moves essentially at the speed of the ground water. Due to the long half-life, radioactive decay between the boundary well and the population well is negligible. Therefore, population well thyroid exposures generally differed by the amount of dilution provided by the well water withdrawn. This means that by establishing an interim exposure limit for the population well (in other words, the nearest downstream public water supply to the disposal facility), an effective limit for the disposal facility boundary is also effectively established for long-lived mobile radionuclides. As indicated by comparing whole body exposures at the boundary well and population well, the combination of radioactive decay for other shorter-lived isotopes such as H-3 or Cs-137 results in significantly reduced exposures at the population well compared with the boundary well.

The analysis boils down to a question of what can be achieved at what price. There is currently no EPA ground-water standard to assess compliance. EPA plans to develop such standards within the next few years and EPA staff has indicated to NRC staff that they expect that the standard will be in the range of 1 to 25 millirem. In the previous discussion, NRC staff indicated it they believed that an appropriate level for exposures at a potential water supply was in the area of 4 mrem. This is within the range indicated by EPA as a probable standard and corresponds to standards set by EPA in 40 CFR 141 for primary drinking water supplies. The results of the case study may be compared to see if a standard in this range is achievable and at what relative level of costs.

The case study appears to indicate that a limit in the range of 4 mrem/year can be achieved with some moderate costs and changes to existing practices. In comparing thyroid exposures at the population well, the exposures appear to fall into 3 or 4 groups of calculated exposures and costs. Exposures for Cases 1-3 and 1A range from 27 to 650 mrem at negligible incremental costs. Exposures for Cases 4A through 4E, in which a series of operational improvements are implemented, range from 2.6 to 25 mrem at generally somewhat higher incremental costs. For Cases 7B through 7D, in which Cases 4A-4C are repeated using a different waste spectrum (waste spectrum 2), calculated exposures range from 0.2 mrem to 0.8 mrem at incremental costs ranging from \$3.4 E+8 to \$3.6 E+8. Case 5, in which wastes in waste spectrum 1 are assumed to be placed in a highly engineered cement walled disposal cells, has calculated exposures in the same range as those for Cases 7B-7D with incremental costs in the range of \$2.1 E+8. Finally, Cases 8 and 9 illustrate even lower exposures (less than 0.1 mrem) at significantly higher costs than the other groups (\$12-13 E+8).

At first appearance, the costs for these 4 groups appear to be in three general ranges: those in the range of small incremental costs (waste spectrum 1), those in the range of moderate incremental costs (\$3.4-3.6 E+8 for waste spectrum 2), and those in the range of high incremental costs (\$12-13 E+8 for waste spectrum 3). However, this appearance should be viewed with some caution. In the last one or two years there has been considerable change in waste form and packaging practices by waste generators. This makes characterization of existing waste generator practices very difficult. Waste spectra 1 and 2 were therefore established to bound existing waste characteristics, with the realization that in many ways waste spectrum 2 represents conditions that waste generators are either at or are moving toward. Although there are currently no regional processing facilities, many if not most of the larger waste generators are compacting compressible waste streams prior to shipment to a disposal facility. License conditions at all existing disposal facilities will shortly require that some resins and filter media be either solidified or packaged in high integrity containers prior to disposal.

This means that the actual cost differential between Cases 1-4E and Cases 7A-7D is not quite as large as indicated. Of the \$374 million differential in waste processing costs between waste spectra 1 and 2, \$36 million is due to the assumed operation of a regional processing facility which compacts compressible waste streams generated by small waste generators. Of the remaining \$338 million, approximately \$40 million is due to the assumed installation of compactors by the larger waste generators and compaction of compressible waste streams prior to delivery to the disposal facility. The remaining $298 million is mostly spent in stabilizing high activity waste streams through solidification and other means. Therefore, discounting the regional processing facilities costs, most of the additional costs associated with waste spectrum 2 either represent activities that many waste generators are already carrying out or represent costs associated with one general way in which existing disposal facility license conditions may be met. Another way in which existing disposal facility license conditions can be met is through use of high integrity containers. Case 10C examines a situation in which the higher activity waste streams are all stabilized through use of high integrity containers and in this case, thyroid exposures are 1.49 mrem at an incremental cost of about $7E+7.

Another consideration is equitability. The incremental costs calculated for Cases 5, 8 and 9 are spread out over a number of waste generators, including those which generate very low activity wastes. Most of the additional costs for Cases 7A-7D and 10C, however, are involved with stabilizing the higher activity waste streams. The latter cases would appear to be a more equitable distribution of increased costs based upon the relative hazard of the waste.

From this, it would appear that a performance objective that requires that existing EPA public drinking water regulations be met immediately downstream of a disposal facility can be achieved with some moderate changes in waste form and packaging techniques and disposal facility design and operating practices. These changes principally include methods by which the stability of the disposal facility may be enhanced:

- o stabilization of higher activity waste streams
- o segregated disposal of stabilized higher activity waste streams from unstable lower activity waste streams; and
- o increased attention paid to reducing contact of water with the waste.

Increased stability of the higher activity waste streams may be accomplished by placing the waste into a stable form (e.g., solidification), use of a stable waste package (e.g., high integrity containers), or through disposal cell design. For example, Class 4C, 7D, and 8 all assume the same disposal facility design but differ in the waste spectrum assumed. The calculated results for each of these cases are as follows:

	Case 4C	Case 7D	Case 8
	Spectrum 1	Spectrum 2	Spectrum 3
Boundary Well			
o Whole body	.1	.1	.1
o Thyroid	12.4	0.5	0.2
Population Well			
o Whole body	.007	.002	.0003
o Thyroid	3.9	0.2	.07

As stated above, the industry is moving toward waste spectrum 2 and therefore does not represent a significant change from existing practice. Spectrum 3, however, represents considerable existing costs.

In the waste spectra considered, the indicated reduction in impacts caused by waste spectra 2 and 3 is a result of two aspects: increased waste stability and improvements in leaching characteristics. The principal gain is believed to be the former (increased stability). Although the analysis does indicate that reduced groundwater impacts can be achieved through increased solidification and gives some indication of the level of impact reduction potentially achievable, it is currently difficult to rely on reduced leaching as a means of limiting impacts. There exists little or no information on the leaching characteristics of solidified waste forms for long lived mobile isotopes such as Tc-99, C-14, or I-129.

The effect of waste stabilization can also be assessed. In waste spectrum 2, all of the higher activity waste streams are stabilized by either solidification or waste packaging techniques. In Case 10C, waste spectrum 1 is assumed and the solidified waste streams are assumed to be stabilized through use of high integrity containers. As shown in Table 5.28, the total cost associated with the case is only $4.62 E+8. Impacts with this case may be compared with an example in which all high integrity containers are assumed to provide stability only. These are as follows:

	Case 10C	Case 10C (Stability Only)
Boundary Well		
o Whole Body	.01	0.1
o Thyroid	4.7	4.7
Population Well		
o Whole body	.004	.004
o Thyroid	1.49	1.49

That is, if the only credit given is to stability, then the performance objective is achievable.

Stability of the higher activity waste streams is also important in that it gives greater assurance that the performance objective can be met even under less than ideal conditions. For example, in Case 10C, the waste is assumed to be segregated and disposed in disposal cells having a thick compacted clay cap. It is useful to consider the impacts if this improved cap did not function as intended. For waste spectrum 1, this may be illustrated by the impacts associated with Case 4A. These impacts may be compared to a similar case in which the higher activity waste streams are stabilized. (The same waste form and packaging as Case 10C only the disposal facility design is the same as Case 4A). The impacts are as follows:

	Case 4A	Case 4A with stabilized higher activity streams
Boundary Well		
o Whole body	4.0	.07
o Thyroid	80.5	20.1
Population Well		
o Whole body	.05	.02
o Thyroid	25.4	6.6

As can be seen, the population well thyroid exposures are only a factor of 1.7 higher than the 4 mrem limit for the stabilized case while for Case 4A the calculated exposures are a factor of 6.4 higher.

Given the selection of a performance objective corresponding to EPA primary drinking water standards (40 CFR 141) at the nearest drinking water supply to the disposal facility, a performance objective may also be set out for potential exposures at the disposal facility boundary. While releases of longer-lived isotopes will be controlled by the performance objective for the nearest drinking water supply, there is a possibility for somewhat higher ground-water impacts at the boundary well due to the migration of short-lived isotopes. In addition, such exposures would impact a reduced number of individuals. For this reason, NRC staff believes a higher dose criteria could be implemented and have selected a close criteria corresponding to current EPA limits in 40 CFR 190 for releases from the nuclear fuel cycle (25 mrem to whole body, 75 mrem to thyroid, and 25 mrem to other organs). Twenty five mrem to whole body and to other organs at the facility boundary is at the upper end of the expected range of the future EPA limit for general ground-water releases.

5.4 OTHER POTENTIAL LONG-TERM ENVIRONMENTAL IMPACT PATHWAYS

This section addresses other potential long-term impacts associated with near-surface disposal of radioactive waste. These impacts may be divided into three areas:

1. Gaseous releases from decomposing wastes.
2. Plant and animal intrusion.
3. Erosion.

Potential ways to mitigate such impacts are also addressed. The details are set out in Appendix M.

5.4.1 Gaseous Releases From Decomposing Wastes

Much of the waste currently being disposed in shallow land burial facilities consists of organic material such as wood, paper, or animal carcasses. As such buried organic material decomposes over time, gaseous decomposition products such as CO_2 or CH_4 (methane) are formed which can be transported upward, through the trench caps, and into the atmosphere. Such decomposition gases can contain tritium (H-3, or T), C-14, or other radioisotopes contained in the disposed waste.

The presence of tritium and carbon-14 tagged decomposition products at shallow land burial facilities was first observed by Matuszek, et al., (see Appendix M). Samples of gases collected from trench sumps at the Maxey Flats, Kentucky, and West Valley, New York disposal facilities have been shown to contain elevated quantities of tritiated gaseous compounds, primarily CH_3T and HTO, but also HT and other tritiated hydrocarbons. Such C-14-tagged hydrocarbons as $^{14}CO_2$ and $^{14}CH_3$ have also been identified as well as Kr-85 and Rn-222.

There are two concerns due to the observed generation of waste decomposition gases within disposal trenches: (1) offsite exposures due to release of radioactive gases, and (2) onsite nonradiological safety to operating crews.

In the former case, potential offsite releases and exposures to individuals do not appear to be significant. Although the existing data is limited, the emanation rates that have been measured at near-surface disposal facilities are small, and would indicate that potential offsite exposures would not be significant. That is, potential exposures would be expected to be orders of magnitude less than limits established in 10 CFR 20 and much less than limits established in 40 CFR 190 for effluents from operation of a nuclear fuel cycle facility. However, additional field investigation could be performed to verify this and to investigate the extent that differences in site design, operation, site climate, seasonal variation, measurement techniques, etc. have upon the emanation rates. For example, the observed differences in tritium emanation rates between the Beatty facility and the Maxey Flats facility may be influenced by the lesser permeability of the cover material at the Maxey Flats facility. The soil was generally saturated when the measurements were taken, which would impede upward gas flow. Other site specific conditions--such as the greatly increased evapotranspiration at the Beatty facility compared with the Maxey Flats facility--may also have an impact.

Decomposition of organic waste and generation of gases is a complex process which is accelerated by moist, saturated conditions and retarded by dry, unsaturated conditions. The former is illustrated by the conditions at the Maxey Flats and West Valley facilities, where waste decomposition has led to increased infiltration and saturated conditions, further accelerating decomposition. The latter situation is illustrated by the Beatty, Nevada facility, which has no water management problems and a greatly reduced rate of waste decomposition. Emanation of the generated gases through the trench cap is a variable depending upon such factors as trench cap thickness and composition. In general, emanation rates would be reduced by thicker covers composed of lower permeable materials.

Key variables, of course, are the composition of the waste material itself, as well as the disposal practices at a particular disposal facility. Compressible, easily degradable organic waste material can lead to water management problems at humid sites as well as increased generation of gaseous decomposition products.

Therefore, essentially the same improvements in waste form and disposal facility design and operation practices that would eliminate the need for active long-term maintenance activities following site closure would also act to greatly reduce the rate of decomposition of the waste material. Such a reduction in the decomposition rate of the disposed waste would not only reduce the instantaneous production rate of gaseous decomposition products, but would also allow time for decay of tritium (half life of about 12 years). Thus, total integrated releases over time would be smaller.

In summary, the emanation rates actually measured from LLW disposal sites are very small, and would be expected to result in very small offsite doses. Even under less than ideal conditions--that is, for example, at Maxey Flats where decomposing waste has produced a bathtub situation--decomposition gases have not resulted in significant releases. Furthermore, such generation rates would be expected to fall off over time. This is the experience seen by EPA for methane generation at nonradioactive solid waste disposal sites.

The second area of concern is of a relatively shorter-term nature--i.e., a potential nonradiological safety hazard at the disposal facility from generation of methane gas. Methane explosions have been observed at or nearby sanitary landfills. This potential concern, however, can be mitigated or eliminated at a low-level waste disposal facility by, for example, reducing the decomposition rate of the waste material. This has already been shown to be important for minimizing the need for active long-term maintenance. In addition, methane gas generation and migration may be readily monitored in sumps and observation wells through currently available techniques. If monitoring shows methane gas generation to be a potential problem, the technology for construction of engineered methane control systems has already been developed for sanitary landfills and chemical and hazardous waste disposal facilities, where methane generation would be expected to be a much greater problem due to the nature of the disposal technology utilized and the typically higher organic content of the disposed waste material. Application of a given methane gas control technology would be applied on a site-specific basis as part of licensing an individual facility.

5.4.2 Plant and Animal Intrusion

The intrusion of deep-rooted plants and burrowing animals into disposed waste could potentially affect disposal facilities in three ways:

- Radionuclides may be brought to the surface where they may be dispersed by wind and water;
- Contamination on or within plants and animals may be potentially eaten by humans; and
- Plant and animal intrusion can create pathways in a disposal trench cover for increased percolation of rainwater into the disposal trench, thus increasing ground-water migration.

Occasional cases of plant and animal intrusion have been documented at disposal facilities operated by the Department of Energy and are discussed in Section 2.2.4

of Appendix F. The uptake and dispersion of radioactivity by plants and animals has not been reported at commercial disposal facilities. The impacts from these documented cases have not been of major public health and safety concern. Actual uptake and dispersion impacts of plant and animal intrusion into disposed wastes would be site specific and difficult to predict due to differences in climate, plant and animal species and waste characteristics. The last effect of plant and animal intrusion--that of increasing percolation into disposal cells--was considered during the ground-water analysis in Section 5.2

In Appendix F, NRC looked at a number of ways in which the occurrence of plant and animal intrusion could be minimized or eliminated, including:

1. Increasing the thickness of earth fill between the top of the disposed waste and the disposal cell surfaces;

2. Placing higher activity material at greater depths;

3. Improvements in waste form; and

4. Using biological barriers such as rip-rap, cobbles, asphalt, root toxins and herbicides.

These are discussed in greater detail in Section 2.2.4 of Appendix F and in Section 2.0 of Appendix M. NRC concluded that the methods that would be applied to reduce impacts to man due to human intrusion and migration would also generally serve to reduce the potential impacts of plant and animal intrusion (e.g., thicker trench caps and placing high or activity waste deeper). With respect to specific engineered biological barriers, NRC concluded that such barriers may be useful as a means of helping to reduce potential ground-water migration to levels as low as reasonably achievable. However, additional work is believed to be needed regarding the application and use of biological barriers before specific requirements for their use could be established. For example, it is believed that the effectiveness of such biological barriers would be seriously reduced as long as instability of the disposal cells was a problem. The presence of the barriers may also make maintenance of unstable disposal cells more difficult and more expensive. NRC therefore concluded that at this time it is of more fundamental importance to concentrate on methods to achieve greater disposal cell stability. Thus, in designing disposal cell covers, plant and animal intrusion should be considered on a site-specific basis but requiring specific actions to include barriers to such intrusion is not believed to be generally appropriate at this time.

5.4.3 Erosion

Another source of potential environmental releases is through the effects of wind and water erosion. Through these mechanisms, the covers over disposal trenches may be removed over time, eventually exposing the disposed wastes which could then be potentially dispersed into the environment through airborne or water-borne pathways. In addition, a significant erosion problem would reduce the predictability of the disposal facility performance over time.

It is recognized that minimizing the effects of erosion is of significant importance when siting, designing and operating a disposal facility. Avoidance of areas which could result in erosion problems has been already addressed in the basic siting considerations set out in Appendix E. The effects of erosion and the types of erosion are site-specific and would be analyzed as part of individual licensing actions for a particular disposal facility. For some facilities--for example, those located in an arid region having high winds--wind erosion may be of most significance. For facilities located in humid environments, gully or sheet erosion due to the action of water may be of most significance. Gully erosion would effect less of the disposed waste, but could occur over a shorter time frame. Sheet erosion would eventually effect a larger area, and hence a larger amount of the disposed waste, but would take longer to occur.

It is believed that the effects of erosion at a disposal facility can be minimized through proper siting, design, and operation to the point that it need not be considered a problem. Practical measures which can be readily taken to minimize or eliminate this potential problem include the following examples:

- Avoid areas characterized by rapid erosion, such as flood plains, areas of high topographic relief, and so forth.
- Stabilize the site against erosion through application of a soil cover such as grass or a layer of rip-rap.
- If drainage channels are used at the facility, minimize gully erosion through appropriate engineering such as lining with rip-rap.

Still, it is instructive to obtain an upper-bound estimate of the level of potential exposures that could occur if through some reason the waste did become exposed through erosion. To do this, an estimate must be made of the length of time that it takes for the cover over the waste to be removed through weathering activities. As stated above, gully erosion could be a fairly rapid process. However, its effects would tend to be localized and if it were to occur, then it would most likely be identified during the 100-year institutional control period. During this time period, the disposal site would be under the surveillance and control of a governmental agency and steps could be taken to correct the problem. Sheet erosion, however, would appear to be a less perceptible, longer-term potential problem.

A discussion of factors which influence wind and water erosion, as well as typical erosion rates in various parts of the country, is provided in Appendix M. For the purposes of this environmental impact statement, a time of 2,000 years is assumed to be required to uncover 2 meters of soil, or about 1,000 years per meter of cover over the disposed waste. This essentially assumes a soil loss of 6 tons per acre per year from the disposal trench. A continuous (over 2,000 years) soil loss rate of this magnitude from the disposal facility is extremely unlikely. It ignores ground cover and other surface engineering measures that would be incorporated into the disposal facility. The loss rate is at an upper range associated with typical farming activities. Such farming activities are unlikely to occur and if they do occur, it would be unlikely that a continual soil loss rate of 6 tons per year would be tolerated by a farmer. Such rates would probably reduce the productivity of the soils to unacceptable levels long before the 2 meters of soil thickness is lost.

In any case, after a time period equal to 1,000 years per meter of cover thickness, the trench covers are hypothetically assumed to be eroded away and the scenario is initiated. As a further conservatism, no credit for waste form is assumed for the erosion scenario. The contaminated exposed soil/waste mixture is assumed to be carried by the water into a surface body water located one kilometer from the disposal facility. The natural mobilization rate calculated for the reference facility (about 0.75 tons/acre/year) is used. The reduction in the activity due to deposition along the route is neglected and the soil/waste mixture is assumed to all dissolve in the surface water, where the water is used by an individual for consumption, crop irrigation, and so forth. The total exposures received by all significant pathways may then be calculated.

Similarly, the effects of wind dispersal of the soil/waste mass exposed by the sheet erosion to the surrounding population are calculated. Details of the calculational procedures used to estimate surface water erosion impacts to individuals and airborne impacts to populations are provided in Appendix G. In these calculations, no credit is assumed for waste form.

The results of these calculations for the 20 cases considered in Section 5.2 in the ground-water migration case study are set out in Tables 5.26 and 5.27. As can be seen, the hypothetical waterborne exposures range from about .1 to 1 mrem to thyroid. All organ exposures are less than 4 mrem/year. Similarly, the hypothetical airborne exposures within 50 miles of the disposal facility range from about 3.5 to 7.3 man-mrem to whole body and from about 70 to 138 man-mrem to bone. The population is assumed to be three times the size of the population within the vicinity of the facility while the facility is operating. As can be seen, such exposures are very small and are an order of magnitude or so below those exposures calculated during the hypothetical operation of a regional waste incinerator (See Chapter 6).

5.4.4 Summary

The previous three sections investigated three additional pathways for potential long-term exposure of the public: gaseous releases from decomposing wastes, plant and animal intrusion, and erosion of the disposal facility. None of these three pathways would appear to result in potential exposures which would exceed the ground-water performance objective developed in Section 5.3.

For each of these potential pathways, there are a number of actions which may be taken to minimize such releases. By and large, such actions also serve to reduce potential exposures to humans through ground-water and intrusion pathways, as well as reduce the need for long-term maintenance of the site. For example, gaseous releases can be reduced by assuring stable site conditions. Erosion is a slow, long-term process which can be controlled through proper siting and good operational techniques. Impacts from plant and animal intrusion can be reduced through engineering designs applied to reduce ground-water migration and potential intruder exposures.

Table 5.26 Population Airborne Impacts from Potential Erosion of the Reference Facility

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(man-millirem/yr)							
1	4.19	80.13	55.32	5.38	21.21	76.43	0.21
2	4.19	80.13	55.32	5.38	21.21	76.43	0.21
3	4.19	80.13	55.32	5.38	21.21	76.43	0.21
1A	4.19	80.13	55.32	5.38	21.21	76.43	0.21
4A	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4B	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4C	3.48	69.52	46.05	5.36	16.14	74.39	0.19
4D	3.48	69.46	46.01	5.35	16.13	74.33	0.19
4E	3.48	69.46	46.01	5.35	16.13	74.33	0.19
5	4.23	84.87	55.02	58.67	18.02	84.85	0.24
6	3.48	69.46	46.01	5.36	16.14	74.39	0.19
7A	3.11	59.29	40.19	3.17	15.21	70.66	0.23
7B	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7C	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7D	6.11	119.8	79.40	64.51	27.50	108.6	0.35
8	6.09	119.8	79.50	64.58	27.51	108.8	0.32
9	4.22	84.81	55.01	58.66	18.01	84.84	0.22
10A	3.48	69.52	46.05	5.36	16.14	74.39	0.19
10B	6.11	119.8	79.40	64.51	27.50	108.6	0.35
10C	6.10	119.5	79.22	64.36	27.43	108.4	0.35

Table 5.27 Individual Waterborne Impacts From Potential Erosion of the Reference Facility

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(millirems/yr to an individual)							
1	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
2	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
3	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
1A	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
4A	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4B	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4C	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
4D	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
4E	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
5	5.23E-2	4.56E-1	9.06E-2	8.79E-1	6.11E-2	2.37E-2	1.17E-1
6	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
7A	6.42E-2	4.93E-1	7.81E-2	9.73E-2	9.73E-2	5.33E-2	8.13E-2
7B	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7C	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7D	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
8	7.49E-2	6.35E-1	1.28E-1	9.82E-1	9.37E-2	4.02E-2	1.68E-1
9	4.69E-2	4.29E-1	8.52E-2	8.74E-1	5.57E-2	1.82E-2	1.11E-1
10A	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
10B	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
10C	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1

Further reductions in impacts from plant and animal intrusion--in particular, further reductions in long-term ground-water releases--may be potentially achieved through use of biological barriers to plant and animal intrusion. Some work has been performed to develop such biological barriers, but additional work is believed to be necessary (particularly in humid environments) prior to setting out criteria for their use. In any case, the effectiveness of biological barriers would appear to be dependent upon the degree of site stability achieved. Ways to achieve improved site stability over time would therefore be of more fundamental importance.

5.5 DEVELOPMENT OF TECHNICAL CRITERIA

Based on the results of the preceding alternatives analyses, NRC selects in this section minimum technical requirements that should be considered and applied in all cases to help ensure that the performance objectives will be met.

The results of the previous analyses indicate that with modest increases in cost relating to improving the form and properties of waste shipped for disposal and modest improvements in the design and operation of a near-surface disposal facility (many of which are being used at some of the existing sites today) the potential health, safety, and environmental impacts from disposal of LLW can be greatly reduced. In addition, the ability to predict the long-term performance and impacts of near-surface disposal facilities is improved and the uncertain and high costs required to care for disposal sites over the long term are reduced.

The minimum requirements developed in this section for near-surface disposal of radioactive waste are directed at four key aspects that are directly related to assuring the overall performance objectives for migration and long-term maintenance are met. These are:

1. Eliminate to the extent practicable, the contact of water with waste both during operations and after closure to reduce the potential for migration.

2. Assure long-term stability of the site and facility to eliminate the need for constant care and maintenance over the long term with attendant uncertain high costs and long-term commitment of social resources;

3. Assure a continuation of state-of-the-art procedures, understandings and techniques for the siting, design and operation of near-surface disposal facilities while maintaining flexibility to accommodate new advances in technology and understandings and to address special waste disposal problems.

4. Improve confidence in the predictability of the long-term performance capability of the facility.

Stability of the LLW disposal facility may be the single most important aspect and is related directly to the achievement of the performance objectives. Continued assurance of protection of the population from migration of radioactivity from a disposal site should not have to rely on the indefinite implementation of maintenance programs periodically or continually to ensure the continued integrity of the site. NRC believes that such instability will lead to situations where indefinite costs and resources will need to be applied for such maintenance programs in the future. In general, the costs for disposal should be paid by those generating the waste today and the need for active major maintenance should be eliminated through proper siting, design, operations, and closure. Thus, NRC's requirements should provide that proper preventive measures are taken today by those generating and disposing of the waste, to provide stability in an LLW disposal facility over the long term, eliminate the need for active maintenance, and reduce potential costs to future generations.

A second aspect, predictability, relates to the need to be able to adequately characterize and analyze the various components or barriers of a disposal system, and assess with a reasonable degree of assurance that they will operate effectively over the long term and will not be subject to any major unpredictable changes during the time that they must remain effective.

The predominant method used to date for disposal of LLW has been shallow land burial. The natural characteristics of the disposal site environment have been principally relied upon to provide confinement of the waste over the long term, although some very limited controls have been placed on waste form, facility design and operations, land ownership, and postoperational considerations. The experiences at several of the existing sites have shown the need to consider a series of "multiple barriers", rather than relying principally on one component (e.g., the site).

It is with these views in mind that NRC has selected minimum requirements addressing each of the four basic components of any disposal facility: institutional controls, site characteristics, design and operations, and waste form and packaging. The following sections present the development of the technical requirements for each of the four disposal system components considering the performance objectives. The requirements are set out in general terms with the intention of setting out the overall intent of the requirements rather then providing precise regulatory wording. They are divided into those involving codification of existing practice and those involving additional new requirements.

5.5.1 Codification of Existing Practice

5.5.1.1 Institutional Control Requirements

1. The land owner shall carry out an active institutional control program to physically control access to the site following transfer of control from the site operator.

2. Each applicant must demonstrate adequate financial resources to cover the estimated costs of conducting licensed activities over the planned operating life of the project.

3. Each applicant shall ensure that sufficient funds will be available to carry out final site closure and stabilization activities.

4. Each applicant shall ensure that sufficient funds will be available to cover the costs of postclosure surveillance, monitoring, and any required maintenance.

The need for active institutional controls at a site was discussed in detail in Chapter 4 regarding control of potential inadvertent intrusion. Such controls are also important from the standpoint of migration since the actions of an intruder could disturb the site surface, increasing the rate of infiltration of rainfall and thus the potential for migration. Such a program is also important with respect to carrying out an environmental monitoring program to help evaluate continued site performance and to carry out any minor maintenance activities that may be needed. Such maintenance could involve filling any subsidence depressions which would serve to reduce the potential for water infiltration. The need for adequate financial assurance is also discussed in detail in Chapter 9.0. Adequate financial assurance will help ensure that the site is properly operated, closed, stabilized and cared for during the active institutional control period. Proper closure and stabilization will help reduce the need for active maintenance over the long term and reduce the potential for migration. An active institutional control program including provisions for adequate funding are a codification of existing practice and the costs have been included as part of those for the base case analysis.

5.5.1.2 Site Characteristics

To develop the minimum site suitability requirements, NRC has followed the practice of tiering, utilizing and relying on existing information and experience to provide a basis for the requirements. A great deal of experience has been gained over the years regarding the handling and disposal of radioactive waste. Based on that experience and experience regarding nonradioactive solid and hazardous (chemical) waste disposal facilities, a number of requirements and recommendations regarding the siting of disposal facilities have been developed by the USGS, EPA and others. NRC has utilized these requirements and recommendations to develop minimum site suitability requirements. These requirements were assumed in the development of the reference disposal facility described in Appendix E and the costs of application of these criteria are reflected in the costs of the reference facility. (It is difficult to individually quantify the impacts of the siting requirements since the performance of the facility is so closely linked to design and operations.) The primary emphasis given by the NRC in developing these requirements was selection of sites with natural characteristics which provide for isolation of wastes, reduced contact of water with wastes, long-term site stability, and predictability of long-term performance as opposed to short-term conveniences or benefits such as minimization of transportation or land acquisition costs.

A wide range of sites, ranging from the humid east to the arid west, are potentially available for use in siting a near-surface disposal facility. NRC has set out what are believed to be common sense site suitability requirements that can be consistently applied throughout the country. The requirements would eliminate from consideration limited areas in each region due to undesirable characteristics, leaving large areas in each region where acceptable sites may be found. The requirements are intended to eliminate, to the extent practicable given the variety of sites anticipated, certain characteristics that are known to lead to or have potential to lead to long-term problems. Each is briefly addressed below and further detail is provided in Section 2 of Appendix E.

1. Requirement: The site shall be capable of being characterized, modeled, analyzed and monitored.

Analysis: The hydrological and geological complexity of the site is important, and influences the ability of the applicant to demonstrate that the performance objectives will be met, to determine and characterize appropriate pathways, to construct a physical model of the site, and to predict the long-term performance capability of the site. Simple subsurface media are preferred for disposal sites so that representative values for input parameters can be determined, a workable model for reliable transport predictions can be developed, and a representative monitoring network can be established to help evaluate the continued performance capability of the site over time.

2. Requirement: The site disposal areas shall be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year flood plain, coastal high-hazard area, or wetland.

Analysis: Avoidance of significant surface water features such as wetlands, swamps, and bogs at site disposal areas will reduce the potential for significant quantities of water being available to enter disposal cells and to leach disposed waste. In addition, these areas frequently are ground-water discharge areas and environmentally sensitive areas which should be avoided. Executive Order 11988 requires avoidance of the 100-year flood plain (Ref. 14). Avoiding the flood plain and coastal high hazard areas will reduce the potential for flooding and erosion of the disposal site.

3. Requirement: Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate the disposal cells.

Analysis: The amount of runoff from upstream drainage areas must be controlled through site selection or diversion to prevent erosion or inundation of disposal cells. Such controls will lengthen the life of covers constructed over the disposal cells and will reduce the amount of water infiltrating into the wastes.

4. Requirement: The disposal site must provide sufficient depth to the water table so that ground-water intrusion, perennial or otherwise, into the waste will not occur.

Analysis: Disposal of the waste above the water table will significantly reduce the amount of water in contact with the wastes. Leachate will be released to the water table only when the soil moisture content exceeds field capacity--typically during the wet season in humid regions and infrequently in arid regions. Engineering design and construction techniques can reduce percolation of precipitation into disposal cells. Providing sufficient depth to the water table will eliminate the influx of significant quantities of water into disposal cells from below. Exceptions to this requirement can be considered when the site's hydrological and geological characteristics are such that diffusion is the predominant means of radionuclide movement.

5. Requirement: The hydrogeologic unit used for disposal must not discharge ground-water to the surface within the disposal site.

Analysis: A long ground-water travel distance between the disposal site and the nearest point of discharge to surface water is desirable to provide time for radioactive decay of radionuclides being transported by the ground water. In addition, the longer travel distance will typically increase dispersion and retardation of the radionuclides by the subsurface media. Providing long travel distance to points of water discharge and use will reduce potential impacts since the amount of activity reaching such locations will be reduced. Thus, it is not desirable to locate a disposal facility within close proximity (e.g., a few hundred meters) of a municipal drinking water well field or to locate disposal cells within close proximity of a perennial steam.

6. Requirement: Areas must be avoided where tectonic process such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives or may preclude defensible modeling and prediction of long-term impacts.

Analysis: The avoidance of these tectonic processes promotes the stability of the disposal facility and increases the simplicity of the site, enabling adequate characterization, modeling, analysis and monitoring. In addition, the avoidance of these processes reduces the likelihood of unidentified pathways of transport or failure mechanisms for disposal cell covers.

7. Requirement. Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the site to meet the performance objectives or may preclude defensible modelling and prediction of long-term impacts.

Analysis: The rationale behind avoiding significant surface geologic processes relates to the desire to avoid active maintenance and exposure of the wastes to these processes. In addition these processes are typically associated with significant topographic relief, the avoidance of which increases the ability to manage surface water and prevent erosion. With respect to surface water management, a slight to moderate slope aids in the runoff of surface water and minimizes infiltration into the disposal unit. However, if the slope is too steep, then the higher velocities associated with runoff water may produce accelerated erosion or may necessitate surface runoff control systems that require active maintenance. Safe construction and maintenance of disposal cells can also be difficult on steep slopes.

8. Requirement: The disposal site must not be located where the operation of nearby municipal, government, commercial or other facilities could adversely impact the ability of the site to meet the performance objectives or significantly mask the environmental monitoring program.

Analysis: The rationale behind this requirement is to avoid the potential effect other facilities might have on a near-surface disposal facility through altering natural ground-water flow patterns, changing the natural moisture content of the soils, modifying the ion exchange properties of the soil and reducing the ability to monitor the performance of the site.

5.5.1.3 Design and Operations

The specific technical requirements on the design and operation of a near-surface disposal facility are principally directed at assuring stability of the disposal facility over the long term; reducing, to the extent practicable, the contact of water with the waste; improving the ability to predict the long-term performance capability of the disposal facility; and helping reduce or eliminate the need for active long-term maintenance operations.

1. Requirement: In general, the site design and operation features should emphasize long-term isolation of the waste, rather than ease of construction and operation, as well as avoiding the need for long-term active maintenance. Site design and operation of the facility should also be carried out in accordance with a plan for final site closure and stabilization and should be directed at complementing and improving the ability of the natural site characteristics to isolate the radioactive wastes. Site closure must be considered prior to disposal site licensing rather than as an afterthought. A site closure and stabilization plan which includes funding for closure and long-term care must be provided as a part of the application. This plan will be reviewed and updated periodically during the life of the site and a final plan must be reviewed and approved by NRC prior to final closure. In addition, after site closure, an observation period is needed between the time that a disposal facility is closed and the time the license is transferred to the site owner. This is to carry out any final active maintenance that may be required and to assure that the site is in a stable condition such that only passive care, surveillance and monitoring is required. Active waste disposal operations shall not have an adverse effect on completed closure and stabilization measures and appropriate closure and stabilization measures should be carried out as each disposal cell (e.g., each trench) is filled and covered. Finally, a buffer zone of land shall be maintained between any buried waste and the site boundary. The buffer zone shall extend at least 100 feet outward from the perimeter of the waste disposal area.

Analysis: One of the principal lessons learned from past experience with LLW disposal is that insufficient attention has been given to the long-term aspects of waste disposal. Short-term considerations such as ease of siting or operations were occasionally given higher consideration than long-term aspects such as the amount of long-term commitment and expense required to maintain the site in a safe condition. Since the principal function of a disposal site is to safely contain disposed waste over the long term in a manner that does not require extensive social commitment (e.g., periodic expensive major site rework), then it is axiomatic that this principal function be given major consideration all throughout the life of the site--that is, from the time the disposal site is licensed through the time that it is operated to the time that it is finally closed. As has been previously discussed, the final condition of the disposal facility should not require extensive maintenance--including extensive repairs of trench slumping or subsidence, or continued pumping and processing of the trench leachate--to maintain the site in a safe condition.

Therefore, any application for a near-surface disposal facility should contain a site closure plan which describes how the applicant will operate and prepare the site for closure and eventual transfer to the site owner (i.e., the state or federal government). Such a plan would have to be approved before a disposal license would be granted. Arrangements to assure that sufficient funds are available for closure and long-term care would need to be provided as part of the plan.

During the operational life of a disposal site, additional data will be obtained regarding the expected long-term performance of the site. The site closure plan should therefore be reviewed on a periodic basis and modified as required to better assure that the overall performance objectives for near-surface waste disposal are met. Such periodic reviews should include a review of the funding arrangements and would most conveniently occur as part of renewals of the operating license. A final site closure plan should be reviewed and approved prior to final closure of the disposal site.

NRC staff believes that a site closure plan which is included with the application for a disposal site and periodically reviewed and updated during disposal site operation is essential for assurance of long-term public health and safety. NRC staff believes that the alternative of a specific site plan--that is, not requiring one and allowing site closure to be addressed when a particular site is filled to capacity--is clearly unacceptable. Such an alternative would ignore the lessons of past experience with LLW disposal.

Site closure of existing facilities has been addressed by NRC. On May 17, 1979, NRC issued a Low Level Waste Licensing Branch Technical Position entitled "Low-Level Waste Burial Ground Site Closure and Stabilization." The objectives of this Branch Technical Position have been incorporated into existing NRC and Agreement State disposal licenses. The specific requirements of this Branch Technical Position are set out in Appendix I.

In this Branch Technical Position, NRC staff also expressed its intent to require a site closure plan as part of any new disposal site licenses (which would currently be licensed under Parts 20, 30, 40, and 70 of the Commission's regulations) and to assess the plan against the 16 objectives in the Branch Technical Position.

The reference facility described in Appendix E assumes application of the Branch Technical Position and the costs and impacts of development and implementation of the plan have been included in the analyses. The costs for development and periodic updates of the plan have been estimated to be in the range of $600,000, or about $0.60 per m^3 of waste ($.02/ft^3). The costs for development of a site closure and stabilization plan for the various alternatives considered in this EIS does not change. The cost for implementation, however, can vary depending upon specific design and operational practices and long-term site stability. For example, Cases 1-3 in Section 5.2 assume, consistent with past practices at most sites, that no special efforts were made to ensure long-term site stability. Thus, the costs and impacts for implementation of the plan for the base case facility were high. This served to provide a base case of what could be expected if past practices were continued and against which improvements to ensure long-term stability can be analyzed and compared. The rest of the 20 cases considered in Section 5.2 considered alternative methods by which such improvements may be made.

The obvious alternative to requiring a site closure and stabilization plan is to not require one. Given the past experience at several of the existing sites and the fact that existing licensees are implementing the NRC Branch Technical Position, NRC did not consider this alternative viable. Other alternatives involve increasing the emphasis on site closure and stabilization and requiring additional actions to those already set out in the Branch Technical Position. Any such changes are reflected in the further specific requirements discussed below.

2. Requirement: Prior to any license application, the applicant shall conduct a preoperational environmental monitoring program to provide basic environmental data on site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, and seismicity of the site. For those characteristics that are subject to seasonal variation, data shall cover at least one full year.

   During disposal facility construction and operation, the licensee shall maintain a monitoring program. Measurements and observations shall be made and recorded to provide data to evaluate the potential health and environmental impacts during construction and operation and enable the evaluation of long-term effects and the possible need for mitigative measures.

   After the site is closed, the licensee responsible for postoperational surveillance of the site shall maintain a monitoring system based on the operating history and the closure and stabilization of the site. The monitoring system shall be capable of detecting migration of radionuclides from the site.

Analysis

These requirements involve a codification of existing practice relating to environmental monitoring at a near-surface disposal facility. The environmental monitoring program should involve 3 principal phases: a preoperational monitoring program to be carried out prior to initiation of operations to provide baseline environmental data against which the changes in data due to operations of the facility can be compared; an operational phase during which the impacts of facility operation are monitored; and a postoperational phase where the long-term performance of the site is continually assessed. The costs and impacts of designing and carrying out a monitoring program are included as a part of the reference facility described in Appendix E and are representative of the types of environmental monitoring programs that would be expected at future sites.

NRC also very briefly examined some alternatives and costs of improving environmental monitoring programs. Two principal areas examined in which environmental monitoring can be improved compared to the reference facility are: (1) increasing the overall reliability of ground-water and surface runoff monitoring, and (2) airborne particulate monitoring. A monitoring system is intended to provide information on the potential movement of radionuclides away from active disposal trench areas, completed trenches, and other areas where radioactive materials are handled. Over the long term, the monitoring system supplies information regarding performance of the site with respect to protection of ground water and protection of the health and safety of the public. The system should therefore be designed so that performance can be evaluated with confidence. Confidence in the monitoring system is afforded when it can be demonstrated analytically that no significant contamination can leave the site without being detected.

The improved ground-water monitoring system analyzed by NRC includes a total of 20 perimeter wells along the restricted area fence (as compared to 10 for the reference facility). Each of these perimeter wells extend several feet into the saturated zone (minimum depth of 19 m). The perimeter wells are sampled quarterly, as opposed to semiannually as in the reference facility. The number of monitoring wells within the trench areas is raised from 15 to 30, and these wells are also sampled on a quarterly basis. The locations of these wells are selected based on an analysis of site hydrogeological characteristics.

In the reference facility monitoring system, surface runoff is not routinely monitored. The improved monitoring system employs a flow activated automatic runoff monitoring system used in conjunction with a discharge channel located at one corner of the site. Flow composite samples are collected monthly and sent to an offsite laboratory for radiochemical analysis. This monitoring system is operated during the 20-year operational period.

The final component of the improved monitoring system is an expansion of airborne particulate monitoring. The three-location airborne particulate monitoring system is upgraded to include ten additional air sampling units, which are situated at various locations within the restricted area. The samplers provide positive additional data regarding the potential for airborne releases from an operating disposal facility. Particulate filter samples are collected on a daily level and analyzed for gross beta-gamma contamination. On a weekly basis, samples from each sample are assumed to be sent offsite to a laboratory for more detailed analysis such as a gamma spectrum analysis.

The benefit of the improved monitoring system would be a greater level of confidence in evaluating the performance of the site. The estimated differential cost for the improved monitoring system is about \$1.90/m^3 (\$0.05/ft^3).

5.5.1.4 Waste Form and Packaging

Several of the minimum waste form and package requirements set out in Section 6.5.2 of Chapter 6 relating to packaging and free liquid also help to minimize the potential for migration.

1. <u>Requirement</u>: Liquid wastes, or wastes containing liquid shall be converted into a form that contains as little free standing noncorrosive liquid as is reasonably achievable. In no case shall the liquid exceed 1% of the volume of the waste.

Analysis: Liquid radioactive waste and the presence of free standing liquid in radioactive waste shipments presents a number of possible health and safety problems, both over the short and long term. These problems are also aggravated by the corrosive nature of some of the liquids. Except for the disposal of liquid scintillation vials, license conditions at existing operating disposal facilities do not allow direct disposal of liquid waste.

The presence of free standing liquids in waste packages can cause a decrease in transportation safety by increasing the potential for the spread of contamination within waste transportation vehicles and by increasing potential exposures to the population along the route of the waste shipment as well as to disposal vehicle drivers. A corrosive free standing liquid serves to accelerate the potential for leakage, and may also present nonradioactive health hazards. (Present DOT regulations in 49 CFR 173.24 and NRC regulations in 10 CFR 71.31 both require that materials should be packaged so that there is no significant chemical or galvanic reaction between the contents and any component of the packaging).

Problems associated with free standing liquids increase once the waste packages arrive at a disposal facility. Operations at disposal facilities involve time spent near or in contact with waste packages. Leaking waste packages can cause increased contamination of and exposures to site personnel, as well as contamination of site grounds and equipment. Contaminated site grounds and equipment must be decontaminated to maintain safe working conditions causing potential additional exposure and contamination of site personnel. A corrosive leaking liquid creates an additional nonradiological hazard during waste handling and decontamination operations, and can possibly damage site equipment. Contamination of the site surface and equipment can also lead to increased offsite releases through the actions of wind and water. Besides increased population exposures, such operational releases effect environmental monitoring programs.

After disposal, free standing liquid in waste packages can potentially increase the migration of radionuclides in that liquid would be immediately available for migration. Corrosive free standing liquids can cause accelerated corrosion of adjacent waste containers and subsequent accelerated leaching of the package contents. Evidence also indicates that the ion exchange capabilities of a site for certain radionuclides may be impeded by very acidic and caustic conditions (Ref. 15).

In view of this, NRC does not consider the alternative of allowing the unrestricted disposal of liquid radionuclide waste, the "no action" alternative, to be acceptable. Rather, NRC has examined to the extent it can be, given current understanding and capability, the establishment of a specific requirement for free liquid.

One alternative for establishment of a free standing water requirement would be to set out allowable levels of free standing liquid as a function of potential radiation hazard, based upon transportation, storage, handling, and disposal considerations. This would, however, be a potentially overly-complicated requirement, and would be difficult to regulate.

A similar situation could occur if a free standing liquid requirement was established based upon disposal considerations. The potential additional impacts of migration of free standing liquids contained in disposed waste are not only radionuclide-specific but site-specific as well.

NRC staff believes that the most workable criteria would be one designed to eliminate to the extent practicable the presence of freestanding liquids, considering existing capabilities. This approach is consistent with current NRC licensing positions regarding radioactive waste solidification systems in reactors as well as with license conditions at existing disposal facilities.

At existing disposal facilities, disposal license conditions have used a basic percent volume limitation in addition to a total content limitation to account for larger waste containers. Some of these license conditions state that waste packages delivered to disposal facilities should contain no free standing liquid. No free standing liquid is then defined as being in trace quantities: not more than 0.5% or one gallon per container, whichever is less. Other site license conditions define no free standing liquid as constituting not more than 1% of the container volume. All the license conditions essentially state that the intent is to reduce or eliminate, to the extent practicable, the presence of free standing liquid, but allow for trace quantities in recognition of current ability to remove and detect free standing liquid and the possible presence of condensate liquid.

Comments filed on the preliminary draft of Part 61 pointed out that a 0.5% and 1 gallon requirement could result in large cost increases in the disposal of certain wastes and could potentially eliminate the use of certain options in meeting the waste stability requirement. NRC does not believe the overall difference between 0.5% and 1% is large. For 55-gallon drums, which constitute most waste packages, a 1.0% limit would correspond to a free standing liquid content of about two quarts. For large containers such as a 170 ft^3 liner, a 1.0% limit volume would correspond to a free standing liquid content of about 10 gallons.

After more experience is gained in development of procedures to detect and eliminate free standing liquid, a more restrictive definition of free standing liquid could be imposed. All of the sites also require that free liquids be noncorrosive. Noncorrosive means having a pH between 4 and 10.

No cost analysis has been prepared for this requirement since it reflects existing practice and is reflected in the costs and impacts of the base case.

5.5.2 Codification of New Requirements

5.5.2.1 Institutional Control Requirements

1. Requirement: For purposes of calculation, active institutional controls shall not be relied upon for more than 100 years.

Analysis: Although this is a new requirement, the analysis for this requirement was carried out in detail in Chapter 4 of this EIS regarding limiting potential exposures to an inadvertent intruder. The reader is referred to Chapter 4 for further details. The 100-year time period was incorporated into the ground-water analyses in earlier sections. That is, after the end of the 100-year institutional control period, the percolation of water into waste disposal cells was conservatively assumed to increase due to potential intrusion by humans, deep-rooted plants or burrowing animals, or other factors.

2. Requirement: After site closure, an observation period of at least 5 years is needed between the time that a disposal facility is closed and the time the license is tranferred to the site owner to carry out any final maintenance required and to assure that the site is in a stable condition such that only passive care, surveillance and monitoring is required.

Analysis: To help ensure that site stability has indeed been achieved, NRC staff will require that a period of time (up to several years) ensue after closure and before a disposal facility operator's license is transferred to the custodial agency. During this period, the licensee would still be responsible for the care of the site and would be responsible for all site maintenance and environmental monitoring activities. This responsibility would be maintained by the licensee until the license is transferred.

Requiring such an observation period of several years between site closure and license transfer has a number of advantages. An observation period by the licensee would help reduce potential long-term migrational impacts and potential long-term costs to the site owner. Based on past experience at humid sites, subsidence problems would be expected to be observed (if they are going to occur) within a few to 7 to 10 years. If subsidence problems do occur, the licensee should take proper maintenance actions including payment of costs for such activities rather than the state or federal landowner. The need for and extent of such maintenance would be well documented at site closure since the licensee would have had 20-30 years of past operational data and experience regarding the behavior of the disposal cells. Potential long-term subsidence problems could then be anticipated, identified, and corrected during the observation period such that the site would be in a stable condition at license transfer and require only passive care, surveillance and monitoring.

During this observation and maintenance period, the licensee would no longer be receiving income from receipt of waste for disposal. The licensee would be expected to try to reduce maintenance costs during the observation period because of their uncertain nature and would try to ensure that the site has been stabilized as much as possible while the site is being operated. Thus, the requirement of an observation and maintenance period will also serve to place an incentive on the licensee to achieve as stable a site as possible during operations. As stated above, this reduces the risk of long-term monetary impacts borne by the site owner.

Requiring an observation period between the time the site is closed and the time the disposal license is transferred is similar to the intent of regulations promulgated in May 1980 by EPA for disposal of hazardous waste. As part of 40 CFR 265.117 ("Postclosure care and use of property; period of care"), EPA requires that the operator of a hazardous waste disposal facility maintain a closed facility for 30 years prior to license termination (See Appendix N). In the EPA case, however, there is no provision for ownership by the state or federal government. In addition, a licensee may petition the EPA to reduce the postclosure time or the EPA may require that the observation period be extended. An interested person may also petition EPA to extend the observation period. In any case, the intent is the same--to require the licensee to ensure that the disposal facility is operated properly prior to closure, or run the risk of elevated maintenance costs after closure.

A disadvantage to the requirement of a postclosure observation period as compared to the alternative of not requiring one is that it would increase costs to the licensee and so increase the costs of disposal. This disadvantage, however, illustrated by considering the no action alternative--that is, not requiring a postclosure observation period--could actually result in equal or slightly increased costs due to the long-term and uncertain nature of such costs.

As stated earlier, most of the potential subsidence problems that have occurred at existing sites have occurred within 5 to 10 years of waste disposal. Therefore, if an observation period were not required, then the site owner could potentially be faced with expenses for carrying out such maintenance activities soon after site closure. The site owner, through the required financial assurances, could possibly allow for these potential expenses by increasing the amount of funds set aside for institutional control activities, thereby increasing the costs for disposal. Thus, disposal costs could increase whether or not an observation period is required. Finally, not requiring a postclosure observation period would tend to increase the risk of higher long-term institutional control costs to a site owner. In addition, a licensee might have less of an incentive to make sure that disposal was accomplished in a manner that assures a stable site over the long term.

A number of alternatives can be considered regarding the length of such an observation period:

1. Specify a fixed length of time followed by license transfer;

2. Specify no fixed length of time, but treat each specific facility on a case-by-case basis; and

3. Specify a minimum length of time, but treat the need to potentially extend the observation period on a case-by-case basis.

NRC staff has selected the third alternative as preferable. A fixed minimum period of time is needed; otherwise, one of the attributes of the observation period--that of providing an incentive to assuring site stability as part of site operations--is lost. A licensee could potentially cut corners on site design and operations directed at assuring long-term stability, and then petition NRC to terminate the license soon after site closure. In addition, NRC staff does not believe that it would be wise to terminate a license after a fixed period of time following site closure without consideration of site-specific conditions. Additional time may be required at some sites to assure that stability has been achieved.

Based upon past experience, NRC staff believes that an observation period of at least 5 years would be appropriate. A disposal site is expected to be operated for 20 to 30 years, and coupled with a 5-year observation period, would provide 25 to 35 years of experience at the site to judge long-term site stability. If major subsidence problems had been experienced in earlier disposal cells during the operating life of the site and are expected to continue for more recent disposal cells, such problems will probably be identified within a 5- to 10-year period after disposal. A 5-year minimum observation period would thus allow the identification of any major subsidence problems, if they are to occur, associated with the last few years of waste disposal operations at the facility. If additional time is required for this maintenance, it can be provided.

The cost for implementing this requirement may be approximated by first estimating the annual costs to the disposal facility operator to maintain the site after it is closed, and then estimating the resulting costs to disposal facility customers, assuming that the observation period costs are passed onto the disposal facility customer during the facility's operating lifetime. Annual costs to the disposal facility operator are estimated (in 1980 dollars) at three levels, corresponding to three levels of site maintenance required. These three levels are:

high:	$263,000/yr
moderate:	$184,000/yr
low:	$91,000/yr

The costs are derived based upon the estimated annual (in 1980 dollars) long-term care costs to the site owner presented in Appendix Q. However, no contingency is included in the high level of maintenance to account for possible occurrences such as extensive leachate pumping and treatment. The costs are then inflated to the start of the observation period assuming an inflation rate averaging about 9% per year. To assure the availability of funds for the observation period, the disposal facility operator is assumed to place a surcharge ($\$/m^3$) on the waste received at the site. Money thus collected is assumed to be placed into a fund or otherwise invested at an average interest rate of 10% per year.

The results of this calculation are presented in Table 5.28 for four alternative observation periods--no observation period, 5 years, 10 years, and 30 years--and three levels of site care during the observation and active institutional control periods. Also shown are the corresponding closure and long-term care (active institutional control) costs, as well as total postoperational costs. All costs are shown as total costs over a 20-year facility operating life to disposal facility customers. (Unit costs may be determined by dividing by 10^6.)

As shown in Table 5.28, the longer the observation period or the greater the level of care, the higher the observation period costs to the disposal facility customer. In addition, as the observation period increases, the long-term care costs decrease. This is due to the accrued interest in the state-operated long-term care fund during the observation period.

Table 5.28 Comparison of Costs for Alternative Observation Periods

Length of Observation Period (yrs)	($ x 10⁶) Assumed Level of Care Required: High	Moderate	Low
0			
Closure	3.67	3.67	3.67
Observe	0	0	0
Long-term care	34.6	14.4	8.5
Total	38.2	18.1	12.2
5			
Closure	3.67	3.67	3.67
Observe	2.39	1.67	0.82
Long-term care	33.0	13.8	8.12
Total	39.1	19.1	12.6
10			
Closure	3.67	3.67	3.67
Observe	4.67	13.26	1.61
Long-term care	31.6	13.2	7.76
Total	39.9	20.1	13.0
30			
Closure	3.67	3.67	3.67
Observe	12.8	8.96	4.41
Long-term care	26.7	11.0	6.46
Total	42.8	23.6	14.5

Total postoperational costs are increased over the base case (no observation periods) costs for all three alternative observation periods. Assuming a 5-year observation period and a moderate to low range in the assumed care level, costs to the facility customer would range between $\$0.82/m^3$ and $\$1.67/m^3$ ($\$0.02/ft^3$ to $\$0.05/ft^3$). However, total postoperational costs, due to the reduced need to place funds into the state-operated long-term care fund, would be increased by only $\$0.40/m^3$ to $\$1.00/m^3$ ($\$0.01/ft^3$ to $\$0.03/ft^3$).

As shown, the requirement of a 5-year observation period would not appear to raise costs to the disposal facility customer operator. The requirement provides insurance to the site owner that he will not be faced with large immediate maintenance costs, as well as reduces the amount of long-term (institutional control) costs to the site owner.

5.5.2.2 Site Characteristics

No new site suitability requirements have been identified based on the analyses. The analyses support those leading to elimination of water and long-term maintenance and leading to a stable predictable site condition.

5.5.2.3 Design and Operations

Two new requirements for design and operations are identified. They are set out below.

5.5.2.3.1 Contact of Waste by Water

> Requirement. The disposal facility shall be designed to eliminate the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal. Covers of disposal cells shall be designed to prevent water infiltration, to direct percolating or surface water away from buried waste, and to resist degradation by surface geologic processes and biologic activity. Surface features shall direct surface water drainage away from disposal areas at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future.

Analysis: These requirements are directed at reducing the contact of waste with water, reducing the potential for percolation of water into disposal cells, providing long-term site stability, and reducing the need for long-term maintenance. They are relatively straightforward requirements and have generally been assumed for the reference facility. Several alternatives for accomplishing these objectives, however, were considered and analyzed by NRC including variations in the thickness, composition, and design of the disposal cell covers, measures to stabilize disposal cell covers, and measures to manage surface water drainage. Each is briefly discussed below. Other alternatives considered and the details for each are set out in Appendix F.

The use of certain of these alternatives will vary depending upon specific site characteristics (e.g., humid vs. arid site). Given this, none of these alternatives discussed are set out as preferred. To maintain flexibility in implementing the Part 61 rule, the specific measures that the licensee would utilize to comply with the above requirement would be analyzed on a site-specific case-by-case basis.

Improved Disposal Cell Covers and Designs

Installation and maintenance of an adequate cover (cap) over the disposed waste is one of the more important (if not one of the most important) considerations at a near-surface disposal facility. The trench cap provides radiation shielding and an infiltration barrier to moisture. A properly designed and constructed trench cover is also important in helping to minimize erosion and direct surface water away from disposed waste.

The role of the trench cap as an infiltration barrier is especially important. If significant quantities of water are allowed to infiltrate through the trench cap and contact the disposed waste, then some of the radioactivity contained in the waste may be leached from the waste and released into the environment. Optimal conditions at a disposal facility, then, would exclude the contact of significant quantities of water with the disposed waste. Minimizing water movement into disposed waste through use of disposal cell covers also reduces the moisture contact of the waste, which helps to reduce the rate of an aerobic bacterial degradation of waste.

In the reference facility discussed in Appendix E, the trench caps are assumed to consist of one meter of backfill to original grade, plus an additional one meter of soil added above the original grade. NRC analyzed alternatives for improving trench cap performance, including improved compaction techniques, thicker low permeable trench covers, and possible use of multiple moisture barriers. Further background information about different possible types of disposal cell covers is set out in Section 2.3.2.1 of Appendix F.

Use of More Densely Compacted, Thicker Trench Caps.

Improvements in cap performance can be obtained through increased attention to compaction of the waste, disposal cell backfill, and the disposal cell cover. Until fairly recently, little attention has been paid to compaction other than that compaction that can be achieved by application of several feet of trench cover, plus driving over trench covers with waste transport and other site vehicles. This is the case assumed at the reference disposal facility. Decreased infiltration and percolation through a trench cover (by reducing porosity and thus permeability) can be inexpensively achieved, however, through use of improved compaction techniques using commercially available compacting equipment such as vibratory compactors. Such compaction would also help to compress the compressible wastes and reduce voids, thus minimizing settlement and subsidence problems. Within the last few years, the operators of a site located in a humid environment have employed a mechanical vibratory compactor to provide additional compression of disposed waste and compaction of trench caps. The disposal site operators have reported that use of the vibratory compactor has greatly reduced subsequent maintenance of filled and capped trenches.

The cost for leasing and operating a vibratory compactor for use at the reference facility are estimated to total approximately $94,000 per year, or add approximately $.05/ft^3 to the unit operating costs. The compactor would be originally used to compact the 1 m of earthen fill down to the approximate level of the original site grade. Then, a 1 m cap would be applied in reasonably uniform 20 to 31 cm (8-12 inch) thick layers and compacted to a minimum 95% of the maximum compactible density test.

Additional thicknesses of clayey cap material could also be applied. For example, an additional 2 meters of clay soil could be applied which would cost an additional $8.40/m^3 ($0.24/ft^3), assuming that the additional clayey soil would be imported at a cost of $3.50/yard^3 from a borrow pit located approximately 10 miles from the disposal facility. (The details of the cost calculation are set out in

Appendix F.) The additional 2 m soil thicknesses would be applied in 8-12 inch layers and compacted using the mechanical compactors.

Use of Moisture Barriers

The second trench cap improvement could involve the installation of single or multiple moisture barriers within a thicker trench cap. As an example of possible use of moisture barriers, four moisture barrier cases were analyzed in Appendix F. The additional costs associated with these examples are shown in Table 5.29.

Table 5.29 Additional Facility Design and Operations Unit Costs For Improved Disposal Cell Covers

Case	Additional Cost
Base Case (Appendix E) 1m backfill to original grade 1m cover above original grade	0
Thicker Denser Cap 2m additional cover above original grade 3m additional cover above original grade	 $ 8.41/m^3 10.89/m^3
Moisture Barrier Case A One bentonite layer applied at 4 pounds/ ft^3 at 0.5m in 2m thicker denser cap	$11.45/m^3
Moisture Barrier Case B One 36mil reinforced hypalon polymer membrane place at 0.5m in 2m thicker denser cap	$11.92/m^3
Moisture Barrier Case C One polymer membrane at original grade and one bentonite clay layer at 0.5m in 2m thicker denser cap	$14.95/m^3
Moisture Barrier Case D two 36 mil reinforced hypalon polymer membranes	$15.42/m^3

Given these alternatives, there are a number of alternative disposal cell covers that can be applied at near-surface disposal facilities which cover a range of costs and lead to reduced impacts. The advantage of the use of the more exotic techniques of applying moisture barriers do not seem apparent but they have been included for purposes of comparison. A principal consideration in the installation of such caps is the stability of the waste upon which the cap is placed since subsidence and compression of the waste would lead to collapse and cracking of the trench cap.

Stabilization and Final Covers

After a cover has been placed over a disposal cell, it is also important that the cap be stabilized by a final cover. A lack of such a final cover can lead to uncontrolled water and wind erosion of the unit caps. Two types of final covers are in general use today: natural vegetation (e.g., grass), and hard surface covers such as cobbles or rip-rap.

A natural vegetation cover at a disposal facility can serve several functions, such as physically stabilizing earth materials, reducing erosion and infiltration of precipitation into the disposed waste, and enhancing the appearance of a site. A thick grass cover, for example, breaks the impact of falling water droplets on the earth surface and reduces the run-off rate from the site, thereby reducing the potential for water erosion. By the same token, the plant roots help to hold the soil in place, thereby minimizing wind erosion.

Water absorbed into plant roots may also be transpired through the plant leaves. It is important, however, that the root systems of cover grasses be of shallow depth to preclude contact with and uptake of radionuclides from the disposed waste. Vegetation species native to the general area of the disposal site are preferable, as these species are more likely to be acclimated to the site climate. A layer of rip-rap or cobbles can also be effective as a final soil cover, particularly in arid climates where it is more difficult to establish a vegetative cover.

As a part of the description of the reference facility in Appendix E, NRC assumed that action was taken to stabilize the cover by establishing a final vegetative cover. The costs and impacts are, therefore, reflected in the base case analysis. Such actions should be continued and required of future sites.

Use of a Highly Permeable Backfill

One way in which the contact of disposed waste by infiltrating water may be reduced is to backfill the disposal trench with a highly permeable material such as sand. Use of the sand backfill would allow percolating water to quickly flow past disposed waste to the bottom of the trench, thus reducing the contact time and the potential for leaching. Use of a sand backfill would also be expected to readily sift down into the interstitial spaces between waste packages and therefore help reduce the presence of voids in a disposal cell.

As part of this, it would also be appropriate to place a layer of sand--perhaps six inches to a foot thick--at the bottom of the disposal cell prior to waste package emplacement. This would reduce the possibility of rainwater falling on an open disposal cell, or water percolating through a closed cap, from collecting and standing around the bottom waste packages. This is especially important when one considers that at existing disposal facilities higher activity waste packages are frequently emplaced on or near the bottom of the disposal trenches to reduce radiation exposure to facility personnel. Water percolating to the bottom of the trench will percolate below the bottom waste packages into the sand layer, and flow into the French drain along one side of the trench. The French drain then directs the water to a sump at the low end of the trench before the percolating water has a chance to contact the lowest waste packages for extended periods of time. The sand layer also provides a smooth trafficable foundation for operation of vehicles such as fork lifts in the trench.

To implement this option, the disposal operations remain essentially the same as before, with the exception that the sand backfill is utilized instead of backfill composed of previously excavated site soils. The 1 m space between the top of the waste and the top of the trench is also filled with the sand backfill. The backfill is obtained from a local borrow pit.

Assuming one million m^3 of the randomly disposed waste at the facility, approximately 65,000 m^3 of sand would be required annually, or approximately 1.3 million m^3 over the 20 years operating life of the facility. This would result in an additional operational expense of approximately $6.70/$m^3$ ($0.19/$ft^3$) above that for the reference facility. Use of a sandy layer on trench floors in addition to use of a sandy backfill is presently part of standard operating practice at the Barnwell, SC disposal facility.

Surface Water Management and Drainage

The proper management of surface water drainage is important in quickly removing precipitation from the site surface and thereby eliminating the contact time and amount of water that will infiltrate the soil. Runoff and drainage, however, should not be so rapid so as to lead to erosion of disposal cell caps.

Surface water management in the reference facility consists of drainage control through grading of the site. Temporarily installed earth berms are used to direct flowing water away from open trenches which are being actively used for waste disposal. Surface drainage through the use of ditching and channelization can be useful in reducing the quantity of water which percolates into the soil. This is accomplished by transporting the runoff water from the site before significant volumes can infiltrate into the soil. The costs and impacts for proper management of surface water have been included in Appendix E. Appendix F, however, presents an example of one method which could be used to improve drainage from the site. The costs and effectiveness of similar types of drainage systems at a real disposal facility would be site-specific. However, the example in Appendix F illustrates the magnitude of the costs involved in such an improved drainage system--i.e., about $7.50 per m^3 of waste ($0.21/ft^3).

Trench Water

At the reference facility described in Appendix E, an approximate one degree slope is provided in the bottom of the trench from end to end and from one side toward a gravel-filled French drain. The French drain runs the entire length on the lower elevation side to provide for collection and drainage of precipitation entering a trench. A gravel-filled sump is located at the low corner of the trench which is used to remove precipitation from the trench during operations.

In Appendix F, the alternative of using a temporary structure such as a weather shield to minimize water contact with waste during operation is also considered and analyzed (Refer to Section 2.3.2.4). The weather shield would be employed to eliminate the amount of rainwater falling into an open trench during precipitation events. Such shields and air support building have been used at some DOE sites to provide weather shielding. Although the use of such weather support shields would eliminate the inflow of precipitation into trenches as they are constructed and filled, they would increase disposal facility costs by about $27/m^3 and would increase occupational exposures as a result of increased in-trench handling of wastes without significant reduction in long-term impacts. NRC, thus, has concluded that the continuation of existing practices such as those described for the typical facility for removal of incipient precipitation from open trenches should continue to be required.

5.5.2.3.2 Stability of Disposal Cells

> Requirement - Compressible low activity wastes shall be segregated from and disposed of separately from higher activity stable noncompressive wastes. Waste stability may be achieved through the form of the waste, the waste packaging, or disposal facility design. Wastes which must be stablized shall be emplaced in an orderly manner that maintains package integrity during emplacement and disposal. Void spaces between waste packages shall be filled with earth or other material to reduce future subsidence within the disposal cell.

Analysis: A major problem that has been experienced at near-surface disposal facilities has been subsidence of disposal cell covers. Subsidence problems observed at disposal facilities have ranged from minor settling and trench cap cracking to extensive cap collapse and creation of large-scale sinkholes. Subsidence is caused by the existence of void spaces within disposal trenches created by degradation of compressible waste such as paper or other combustible trash and by void spaces within waste packages and between waste packages after disposal. Problems which have been observed in the past at disposal facilities have included:

- Increased percolation of water into the disposed waste, resulting in potentially increased ground-water migration.
- Creation of leachate accumulation problems at two disposal facilities located in humid environments.
- Greatly increased site maintenance costs at some sites which were not expected when the waste was disposed.
- At an arid western disposal facility, exposure of disposed waste which was then dispersed by wind.
- A reduction in the ability to predict the long-term impacts of disposed wastes.

The control of subsidence and assurance of site stability is of major importance in the design and operation of a near-surface disposal facility. Any improvements in trench covers (previously addressed) would be directly related to the stability of the underlying waste. The following subsections review a number of alternative facility designs and operating practices which could be used to help control subsidence problems. These designs and practices generally involve ways in which voids can be reduced in disposal cells, and include waste emplacement and segregation techniques, improved trench compaction, use of grouting and controlled density fills, decontainerized disposal, and increased volume reduction. The use of engineered structures such as caissons and concrete walled trenches are also reviewed.

Waste Emplacement and Segregation

In general, waste emplacement at existing disposal facilities is accomplished by either random disposal (including dumping or rolling of containers into the disposal trenches, and placement of heavier items in a random fashion), or by stacked placement of items in some orderly or interlocking fashion. Stacked emplacement is used to either maximize trench space utilization or provide waste-shielded "pockets" in which higher activity containers may be placed. Variations of stacked emplacement have been used, including individual placement of stacked boxes, large right cylinders, and some individual smaller (200 liter) drums in specific spots. In cavities formed by these first-layer containers, higher-activity waste may be placed. Lower level waste may be then randomly stacked or rolled, depending on the mode of off-loading that is most efficient, on top of the first-layer containers. The stacking height is dependent on the types of containers received, the capabilities of the waste handling equipment, and the backfill required to maintain desirable radiation levels. Random waste emplacement with some stacking of large boxes and containers has been assumed for the reference facility described in Appendix E.

Variations in emplacement practices can directly affect the overall performance of the disposal facility. Container placement can affect future cap maintenance requirements as well as affect the potential ground-water migration of radionuclides from the disposal site.

Stacked Emplacement Disposal: One alternative that can be applied is to stack waste packages rather than randomly dump them. An expected advantage from the use of stacked rather than random placement of waste containers is that of enhanced stability of the disposed waste, resulting from a reduction in trench void space and an associated decrease in the potential for subsidence. The integrity of the trench cover would be enhanced and the infiltration of rainwater reduced, thus reducing the potential for ground-water migration. Stacked emplacement is also estimated to improve the trench volume use (disposal efficiency) from about 50% to about 75%, resulting in an effective 50% increase in trench capacity. Additional positive features of stacked emplacement include a reduction of stresses on the integrity of waste containers, more control over high activity containers, and use of other waste (instead of backfill) for shielding. Where trench space is at a premium and a sufficient fraction of the incoming waste packages have uniform configurations for stacking, it may be to the operator's advantage to use this method.

There are also disadvantages to stacking of waste containers. Stacking is a more labor-intensive effort compared with random placement. For containers requiring individual attachment to offloading devices, such as large (170 ft^3) liners or high activity drums, a reasonably conservative increase in manpower (or decrease in waste emplacement rate), of about 20% over random placement requirements is estimated to occur. For smaller containers such as drums, which are often rolled off of transport vehicles into the trenches, the labor requirements may be increased by as much as a factor of 4. This translates into an overall estimated increased labor requirement for waste handlers of about 1.5, when compared with random emplacement of all container types. This not only increases the labor cost per unit volume, but raises worker radiation exposure levels proportionately. Where segregation of high activity waste is not performed, trench radiation levels may at times also prohibit workers from assisting in desired positioning of containers.

Estimated changes in operational costs and impacts were assessed in Section 5.2. The details are summarized in Table 5.10. As shown, extensive use of stacked disposal for all waste packages is estimated to result in increasing operational costs by approximately \$22/m^3 (\$.63/ft^3). Overall radiation doses among waste handlers would also rise. These additional exposures could be possibly reduced if stacked disposal was carried out concurrently with a program to segregate wastes having higher surface radiation levels.

<u>Waste Segregation</u>: A second alternative that can be applied involves segregated disposal of high activity stable waste streams from low activity unstable waste streams. This alternative was determined to be preferred in the preceding analyses.

Given the mix of waste that is received for disposal, the trench subsidence problems created by disposal of compressible low activity trash waste with the more stable higher activity wastes, and the increased migration potential for the higher activity wastes with increased percolation through the trench cap, an initial conclusion would be to place all of the waste into a solid, noncompressible form such that long-term stability was assured. Such a requirement would help ensure stability, but would require the same level of treatment for all wastes regardless of hazard potential and the costs for disposal of low activity, short half-lived wastes would be high. A more cost-effective alternative to placing all the waste into a stable form would be to segregate and dispose of the low activity compressible wastes separately from the higher activity wastes. The higher activity wastes would be required to be stabilized to provide greater stability over the long term with decreased potential for migration. With segregation, the most innocuous wastes having limited activity and short half-lives could be disposed of under less stringent requirements since they would present minimal hazard potential from the standpoint of migration. More hazardous and longer half-lived wastes could concurrently be placed in a stable form and disposed in separate trenches. Although this concept is not a radical departure from current techniques, it will require that wastes requiring segregation from other wastes be identified on shipment manifest documents and be properly labelled.

The overall costs and impacts of waste segregation were analyzed in Section 5.2. These additional costs are expected to be relatively minor--i.e., an additional $6.10/m^3$ ($0.17/ft) in design and operational costs. This increase is due to the assumption that additional radiation workers will be needed to carry out segregated disposal operations as well as additional equipment leasing costs.

Decontainerized Disposal: Another alternative that could be applied to achieve greater stability is decontainerized disposal of low activity compressible waste streams. Decontainerized disposal refers to emplacement of wastes without any external shipping container. Presently, wastes such as bulk low activity material (e.g., calcium fluoride wastes) or large pieces of machinery are occasionally disposed of at disposal facilities without external shipping containers. This disposal technique could be extended to other low activity wastes, particularly compressible wastes such as dry trash, and biological wastes.

For decontainerized disposal, waste streams would be disposed of by methods similar to that employed at a sanitary landfill. Waste containers would be emptied onto the ground and periodically covered over with a soil layer using heavy equipment. The waste containers could then be decontaminated and reused. For decontainerized disposal, benefits would be realized both during and after disposal operations. The absence of containers would reduce waste volume, with additional savings occurring through container reconditioning and reuse. However, the major advantage would come from accelerated stabilization of disposal trenches.

A major disadvantage is the accompanying hazard of potential airborne contamination to the waste emplacement labor force and transport of contamination to the offsite environment. The costs and impacts were summarized in Tables 5.12 and 5.13.

Engineered Supports for Disposal Trench Covers

As discussed in the previous sections, waste stacking, waste segregation, and improved compaction all appear to offer improvements in the ability to reduce voids and to control (and possibly eliminate) subsidence. Decontainerized disposal would also reduce trench subsidence, and would be useful for such wastes as low activity bulk solids, contaminated building rubble, or occasional large pieces of machinery, provided that disposal of such wastes was carried out in an operationally safe manner and that disposal cell voids were eliminated during disposal. However, decontainerized disposal appears to be currently a nonviable option for general extension to all wastes.

Other types of alternatives could be used such as engineering supports for trench caps including caisson disposal, walled trench disposal, and grouting and controlled density fill. Caissons and walled trenches are examples of "engineered structures" disposal methods. These disposal concepts are reviewed briefly below.

Caisson Disposal: In addition to reducing exposures to site personnel during waste disposal operations as well as reducing potential impacts to a future inadvertent intruder, caisson disposal may be used as a means of providing support against subsidence and of reducing potential ground-water impacts.

In Appendix F, an example case was considered in which 10% of the waste delivered to the reference disposal facility was disposed using caissons. The additional costs for such disposal were estimated at about \$126 per m^3 of waste disposed in caissons, or about \$6.13/ft^3. Although caissons may be considered as a viable option for disposal of some high activity wastes, it would appear to be very expensive and wasteful of land for extension to all wastes. Much of the waste thus disposed would be of very low activity, and use of this elaborate disposal method for such wastes would not appear to be necessary to ensure protection of public health and safety. Difficulties would also be encountered in disposal of odd-shaped waste such as contaminated machinery or disposal of wastes shipped in large boxes.

Walled Trench Disposal: Concrete walled trenches may also be used as a means--albeit expensive--of providing stability and structural support for improved disposal cell covers. Waste is assumed to be stacked into the walled trenches, and then covered with a concrete cap. In Appendix F, two cases using walled trenches were considered: one case in which walled trenches were used to dispose of approximately 100,000 m^3 of waste and another case in which the concrete walled trenches were used to dispose of 1,000,000 m^3 of waste. The costs calculated for these cases were \$256 and \$161, respectively, per m^3 of disposed waste (\$7.25/ft^3 and \$4.56/ft^3). Occupational exposures from using the walled trenches were also estimated to be high, as well as the land use.

Grouting and Controlled Density Fill: Another method available to reduce subsidence is to fill the void spaces between waste packages with a material that will help support the trench cap. The types of agents available for void space filling include clay (bentonite) slurries, and grout, and a controlled density fill.

The use of grout which would be pumped into the void spaces between containers before backfilling appears most practical for trenches where stacked emplacement has been employed. The waste would need to be emplaced in layers and after each layer is completed, the trench would be grouted. The grout would be pumped through tremie pumps lowered to the base of the trench through void spaces between the waste packages at perhaps 6 to 8 separate locations until the grout level reached the top of the first waste layer. The pumping activities generally would be carried out in stages (grouting each layer in sections). After the first waste layer is grouted, additional waste emplacement could proceed. Each layer of waste would be similarly grouted.

Grouting would necessarily have an affect on the overall operations. The grouting operation for each layer would probably consume at least one to two weeks of time. In order that waste disposal operations not be halted during grouting, it would be necessary to operate with two or more trenches open concurrently. The labor force would also have to be augmented. Additional supplies and equipment required would include grouting equipment (pumps, hose, and tremie pipes), a batch cement mixing plant, and cement. A storage area would also be needed for warehousing the large quantities of cement required. The estimated differential cost for this disposal option is \$60.50/m^3 (\$1.71/ft^3). The resultant benefits include greater trench cap integrity, additional intruder protection, and increased resistance of the waste to leaching.

A second case would involve use of controlled density fill in place of the cement grout. In this example, the controlled density fill is assumed to be a commercially available lower strength concrete. The material is emplaced in layers using tremie pipes in a similar manner as the grout fill. The principal difference is cost because the low density concrete is considerably less expensive than high grade cement. The estimated differential cost for the controlled density fill is $47/m^3$ ($1.33/ft^3$). Other than cost, the only appreciable difference in the final trench status is the overall strength of the fill. Controlled density fill will adequately support the trench cap but is more capable of being excavated than high grade cement. Therefore, the controlled density fill provides slightly less intruder protection. The benefits to trench cap integrity and leach resistance are assumed to be equivalent to that for grout cement.

An additional disadvantage is that grouting activities are expected to significantly increase occupational exposures at the disposal facility.

5.5.2.4 Waste Form and Packaging

1. Requirement: Certain high activity waste streams shall have structural stability. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste into a disposal container or structure that provides stability after disposal. Void spaces within the waste and between the waste and its package shall be reduced to the extent practicable. The waste must maintain its physical dimensions and consistency under the conditions of compressive load, radiation, and biodegradation expected to be encountered in disposal.

Analysis: The long-term stability of the disposal site has been previously discussed in detail and is quite important for several reasons:

1. A stable foundation is needed for the trench cover to preclude slumping, collapse, or other failing of the trench cap;

2. The need for active long-term maintenance is reduced; and

3. The ability to predict long-term performance improves.

NRC considered several alternatives that could be applied to help ensure long-term stability. These included use of walled trenches, caissons, grouting, waste processing (e.g., incineration of compressible wastes), and waste segregation. Based on the analyses presented in Section 5.2, NRC has selected segregation of waste as the preferred alternative since it provides the most cost-effective solution. The short-lived low activity wastes which present low hazard potential over time can continue to be disposed of in separate segregated disposal cells provided they meet the minimum waste form operational safety requirements (See Chapter 6). Other longer-lived and higher activity wastes would be subject to the stability requirements. Given selection of segregation as part of the preferred alternative to provide long-term stability of the higher activity wastes, questions remain as to the method or methods that could be applied to place the waste into a stable form, the definition of stability, and the concentration of various radionuclides that would require stability over the long term.

With respect to stability, NRC examined a range of alternatives to achieve stability. Each varies with respect to cost and impacts, but each provides a means for assuring long-term stability. Consistent with maintaining maximum flexibility in implementation of the preferred requirements, NRC has not selected any option as a preferred alternative. Rather, NRC would prefer to allow licensees the flexibility of using a range of options to account for individual differences, site-specific disposal facility conditions, preferences and unique cost-benefit considerations for particular wastes which cannot be dealt with in this EIS. These options include:

- The form of the waste, as generated;
- Processing the waste into a stable form;
- Use of a high integrity container; and
- Disposal facility design.

Each is discussed in further detail below, including the incremental costs and impacts of implementation. Chapter 7 on waste classification presents the results of analyses from which radionuclide concentration guidelines for stable wastes are established. The discussion below reviews the definition of stability including the time over which the waste must be assumed to be stable. NRC has concluded that every attempt should be made to eliminate void spaces within waste and between waste and its packaging as a matter of routine operations at any licensed facility generating waste. The increased cost for this seems minimal since it principally involves only closer attention to the packaging of waste. The costs and impacts for compaction of waste is included under waste processing below.

Form of the Waste as Generated

In many cases the form of the waste itself will be adequate to provide long-term stability, provided that the waste is not packaged with other compressible, degradable material. This is expected to be the case with wastes such as sealed radioactive sources, activated structural steel from a nuclear reactor and contaminated concrete where there are essentially no voids within the waste (or waste package). Some increased costs would be required for these wastes to meet a structural stability requirement. The impacts from disposal of such wastes would be reduced, however, due to decreased water infiltration and leaching over the long term that would be characteristic of a stable disposal area. Long-term care requirements would also be reduced.

Processing the Waste into a Stable Form

Processing of the waste into a solid stable form could involve wastes which are in a wet form such as evaporater bottoms, resins, and filter sludges; and loose compressible wastes such as paper trash. There are several alternatives for treatment of each which generally fall into one of the following two categories:

- o Solidification using a media such as concrete or synthetic polymer;
- o Incineration followed by solidification.

Solidification: There are a number of solidification processes that are currently in use or are being actively marketed. These include cement, urea formaldehyde, and other synthetic polymers such as vinyl ester styrene, epoxy, and bitumen.

Both cement and urea-formaldhyde solidification systems are currently used by light water reactors. Bitumen and vinyl ester styrene are being actively marketed. Other synthetic polymer systems are being evaluated in laboratory and pilot scale studies. Because of the number of potential individual solidification systems that may be marketed and thus the large number of possible variations that could be applied, NRC grouped the systems into three broad scenarios to provide a manageable number for evaluation while still covering the range in waste form characteristics that could be expected. Solidification scenario A assumes a continuation of existing practices and assumes that 50 percent of a particular waste stream is solidified using urea-formaldehyde systems and the other 50 percent using cement systems. Solidification scenario B assumes improved waste performance characteristics over the previous case. It assumes that 50 percent of the waste stream is solidified using cement systems and the other 50 percent using synthetic polymer systems. Solidification scenario C assumes further improved waste performance characteristics achievable with the currently available technology. In assumes that all the waste is solidified using synthetic polymer systems.

The costs and impacts of application of these three solidification types to light water reactor evaporator bottoms, resins and filter sludge waste were assessed in Section 5.2.

Incineration: The incineration of waste is not usually specifically directed at achieving a stable waste form. But, in addition to increasingly specific activity through reducing the volume of waste, incineration of certain wastes does lead to an improved and stable waste form. This is particularly evident in the incineration of biowastes, organic and other liquids, and trash. The resulting ash and solids remaining after incineration could then be solidified or placed in a high integrity container for disposal. Several waste streams were identified in Section 5.2 which could be treated by incineration.

Use of High Integrity Containers

NRC also considered the use of a high integrity container in lieu of solidification. Presently, there is less available information about the design characteristics of specific containers. Several containers are under evaluation and there do not appear to be any insurmountable technical problems involved in their use. At least one high integrity container is being marketed today. To maintain maximum flexibility in meeting the structural stability requirement, NRC believes the high integrity container should be maintained as an option. In addition to providing stability, such a container can also provide equivalent or better performance with respect to containment of the waste after disposal. In some cases, such containers should be applied (e.g., in the disposal of large quantities of short-lived very mobile nuclides) to provide initial containment of waste for decay. Their use in this case should be evaluated on a case-by-case basis.

Disposal Facility Design

In this option, disposal facility design is utilized to provide stability in the same way as the high integrity container does. Several design options including use of caissons, walled trenches and grouted backfill were considered and evaluated. The reader is referred to Section 5.2 and Appendix F for information on these design modifications.

Definition of Stability

As concluded, long-term stability is important with respect to reducing potential impacts to an intruder, reducing potential for migration and reducing the need for long-term maintenance. A specific definition of stability is needed in measurable terms. NRC staff believes that disposal cell subsidence of about 1 to 1.5 feet can be tolerated without significant long-term effects. When considering individual disposal cells, a 1 to 1.5 foot substance would translate into about 5% of the assurred reference facility 8 m disposal depth. NRC staff also considered the weight that a package would receive if emplaced on the bottom of a trench covered by other emplaced waste packages and overburden. Assuming that the other packages were concrete with a density of 120 lbs/ft^3, and also considering additional overburden, a conservative value of 50 psi is derived.

REFERENCES

1. Oztunali, O. I., et al., Data Base for Radioactive Waste Management, Volume 3: Impacts Analyses Methodology Report, NUREG/CR-1759, Dames and Moore for U.S. NRC, to be published.

2. Aikens, A. E., et al., Generic Methodology for Assessment of Radiation Doses from Groundwater Migration of Radionuclides in LWR Wastes in Shallow Land Burial Trenches, AIF/NESP-013, Dames and Moore for Atomic Industrial Forum, December 1977.

3. Wild, R. E., et al., Data Base for Radioactive Waste Management, Volume 2: Waste Source Options, NUREG/CR-1759, Dames and Moore for U.S. NRC, to be published.

4. U.S. Environmental Protection Agency, Preliminary Report: Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, EPA Office of Radiation Programs, August 1979.

5. Macbeth, P. J., et al., Evaluation of Alternative Methods for the Disposal of Low-Level Radioactive Wastes, NUREG/CR-0680, Ford, Bacon and Davis, Utah for U.S. NRC, July 1979.

6. Trigilio, G., Volume Reduction Techniques in Low-Level Radioactive Waste Management, NUREG/CR-2206, Teknekron, Inc. for U.S. NRC, to be published.

7. Chem-Nuclear Systems, Inc., High Integrity Container Systems, November 17, 1980.

8. Personal communication from Marty Carson, Chem-Nuclear Systems, Inc. Director of Domestic Nuclear Marketing, to G. W. Roles, U.S. NRC, June 12, 1981.

9. U.S. Nuclear Regulatory Commission, Final Rule: 10 CFR 20, Standards for Protection Against Radiation; Biomedical Waste Disposal, Federal Register, 46 FR 16230, March 11, 1981.

10. Brauer, J. K., et al., Natural Iodine and Iodine-129 in Mammalian Thyroids and Environmental Samples Taken from Sites in the USA, Environmental Surveillance Around Nuclear Installations, Vol. II, Proceedings of a Symposium, Warsaw, November 5-9, 1973, IAEA Publication, IAEA-TM-180/34, 1974.

11. Palms, J. M., and V. R. Veluri, A Summary of the Analysis Associated with the Environmental Impact of ^{129}I Released by the Barnwell Nuclear Fuel Plant, Emory University Report EMP-122, July 1974.

12. Leddicotte, G. W., et al., Suggested Quantity and Concentration Limtis to be Applied to Key Isotopes in Shallow Land Burial, Management of Low-Level Radioactive Waste, Volume 2, Pergamon Press, New York, 1979.

13. Rogers, V. C., A Radioactive Waste Disposal Classification System, NUREG/CR-1005, Ford, Bacon, and Davis, Utah for U.S. NRC, September 1979.

14. Executive Order 11988, Floodplain Management, May 24, 1977.

15. Nishita, H., et al., Effect of Soil Type on the Extractability of ^{237}Np, ^{239}Pu, ^{241}Am, and ^{244}Cm as a Function of pH, NUREG/CR-0997, University of California for U.S. NRC, September 1979.

Chapter 6

OPERATIONAL SAFETY

6.1 INTRODUCTION

The function of a near-surface radioactive waste disposal facility is to contain disposed radionuclides over the long term, and potential long-term impacts are of major concern in licensing an LLW disposal facility and in determining disposal requirements for specific types and forms of waste. However, protection of public health and safety during the operational phase of the disposal facility is also of concern when licensing the facility and regulating its operation. For completeness in this environmental impact statement, therefore, potential exposures to the public due to offsite radiological releases during site operations are considered. Potential public exposures during site operations can be classed as either "normal" or "accidental," and are discussed below including consideration of potential occupational exposures. A performance objective for operational safety and technical requirements is developed. Also considered is the processing of waste at a regional processing center which for purposes of analysis in this EIS is assumed to be located at the disposal facility.

6.2 POTENTIAL PUBLIC IMPACTS DURING OPERATIONS AT THE DISPOSAL FACILITY

Normal operational releases at an LLW disposal facility can potentially occur through two principal routes: small spills and releases due to normal waste handling and disposal operations; and larger spills and releases due to operational accidents such as a dropped container or a fire. Releases have also occurred at some existing sites as a result of water management programs involving evaporation and treatment of trench leachate. Since the need for such active maintenance programs should be eliminated in the future, releases from such programs were not analyzed.

6.2.1 Potential Public Impacts From Small Spills During Normal Operations

Small leaks and spills from waste containers during normal operations can potentially be released to the air or contaminate the ground surface which can then be carried off of the site by the actions of wind or precipitation run-off. In addition to potential public exposures, surface runoff from contaminated ground surfaces can interfere with the facility environmental monitoring program. For example, at the disposal facility (now closed) located near Maxey Flats, Kentucky, small quantities of radioactivity have been found offsite. Much of this radioactivity is believed to be due to runoff from surface contamination. The presence of this runoff contamination has increased the difficulty of determining other potential modes of offsite release, such as ground-water migration.

It is believed that the contamination of the ground surfaces at the Maxey Flats facility was caused by earlier cases of inadequate waste handling and site maintenance procedures. It is known that waste packages delivered to the facility frequently failed to properly contain the waste within the packages and/or ruptured during emplacement operations. In addition, bulk liquid shipments were often delivered to the facility for solidification prior to disposal. It is believed that insufficient care was taken in handling the bulk liquid delivered.

At currently operating facilities, however, considerably more attention is being paid to minimizing potential surface contamination. For example, disposal facilities currently in operation have procedures to survey facility areas on a routine basis, as well as when possible contamination is suspected. Allowable contamination limits have been established at operating facilities for buildings, grounds, and equipment. (The operational contamination limits for one facility are provided in Appendix E.) These contamination limits may then be inspected against for compliance. In addition, monitoring programs at all operating facilities have been improved and routinely sample for onsite surface contamination.

For example, Table 6.1 is a summary of analyses for soil samples collected in 1978 at the four corners of the commercial disposal facility operated by U.S. Ecology, Inc., and located in the center of the Hanford Reservation near Richland, Washington. The samples were collected and analyzed by the Washington State Department of Social and Health Services (Ref. 1). The state environmental monitoring sample collection is in addition to the licensee's environmental monitoring program.

The isotopes sampled include those from fallout as well as naturally occurring radionuclides. Also shown is a range of soil samples collected in various parts of the Hanford Reservation by DOE (Ref. 2). Within the last few years, both Washington State and U.S. Ecology have expanded their monitoring programs.

Also of interest are the environmental monitoring results for the Barnwell, South Carolina disposal facility operated by Chem-Nuclear Systems, Inc. (CNSI). This facility currently accepts approximately 50% of the low-level waste in the country and approximately a year ago accepted about 70%. Given the large volume of waste received at the facility, most of the operational impacts associated with low-level waste disposal would be expected to be associated with this facility.

For example, Table 6.2, obtained from Reference 3, is a typical set of analytical results of soil samples collected both onsite and offsite. As can be seen, the concentrations of Co-60 and Cs-137 measured onsite are within the range of measurements of samples collected offsite.

Thus, there appear to be no significant releases of radionuclides from the operating sites from surface contamination. This is principally due to increased attention by facility operators to minimizing facility contamination. The practice of delivering bulk liquids to disposal facilities for solidification has been discontinued. All disposal facilities have license conditions that

Table 6.1 Soil Samples Collected at Boundaries of U.S. Ecology Disposal Facility Located in Center of Hanford Reservation

(pCi/gm)

					DOE*	
Isotopes	NE	NW	SE	SW	Min	Max
Ce-144	.27	<.14	<.15	.24	**	.62
Cs-137	.62	.08	.24	1.2	.06	1.9
K-40	16	14	11	15	12	18
Ra-226	.63	.45	.57	.64	.46	.91
Ru-103	.06	<.05	<.05	<.05	-	-
Ru-106	.33	<.28	<.28	.37	.40	.98
Th-232	.45	.60	.80	.69	-	-
Th-238	.63	.59	.60	.62	-	-
U-238	.86	.43	.87	<.67	.07†	.66†
Gross Beta	17	17	16	17	-	-

*From ERDA-1538 (Ref. 2).

**Less than the analytical limit, which is 0.1 pCi/gm.

†Total uranium.

Table 6.2 Soil Samples from Barnwell, South Carolina Disposal Facility

Date	Location	Analysis	Result pCi/gm Dry
092879	C-2	Gamma Scan	^{137}CS <6.2E-01 ^{60}CO <5.4E-01
092879	C-6	"	^{137}CS <1.5E+00 ^{60}CO <1.1E-01
092779	*CN-14	"	^{137}CS <2.0E+00 ^{60}CO <1.2E-01
092879	1-4	"	^{137}CS <1.6E+00 ^{60}CO <3.3E-01
092879	J-4	"	^{137}CS <2.3E+00 ^{60}CO <6.6E-01
092879	H-3	"	^{137}CS <1.2E+00 ^{60}CO <6.5E-01
092879	K-5	"	^{137}CS <1.9E+00 ^{60}CO <8.3E-01
092879	1-3	"	^{137}CS <1.0E+00 ^{60}CO <4.7E-01
092779	*CN-21	"	^{137}CS <1.6E+00 ^{60}CO <5.6E-01
092779	*CN-07	"	^{137}CS <1.0E+00 ^{60}CO <1.2E-01

*Onsite samples, all other samples are offsite.

restrict wastes delivered to the disposal facilities to dry solids, and include restrictions on the amount of free standing liquids allowed in the waste. Compliance with Department of Transportation Regulations is also required. Improvements in waste form and packaging required to protect the inadvertent intruder, improve stability and reduce potential for migration will also reduce the potential for surface contamination and subsequent release to offsite areas.

Other sources of normal operational releases may be from treatment of rain water that may collect in disposal facility trenches. As discussed in Appendix E, disposal trenches are typically sloped toward one side and one end so that precipitating water will flow toward a sump where it can be collected and treated by such methods as solar evaporation. Waste emplacement takes place at the high end of the trench, so that water will flow away from exposed waste packages. The potential for water to contact waste packages is reduced by restricting the amount of waste which may be emplaced before covering with soil. A further reduction in contact time can also be obtained by emplacement of a sandy base for the waste packages and by using a sandy backfill material.

Since releases during normal operations due to spills have not been significant and are not expected to be significant in the future, NRC conducted no detailed analysis of these potential pathways of release and potential public impacts. The impacts from a potential accident (e.g., dropped container or fire) at the site are larger. These two pathways are analyzed in the next section.

Finally, additional information regarding the potential for releases of radionuclides can be obtained through minor and relatively inexpensive improvements in disposal facility environmental monitoring programs. For example, as discussed in Appendix F, a network of 10 continuous air samplers installed at the perimeter of the reference disposal facility is estimated to cost approximately $9,000 (plus installation charges and other indirect costs) and $25,000 per year for sample analysis. This would be estimated to add an additional $0.05/ft^3$ to the operating costs for the reference disposal facility. These samplers can be very useful in locating and correcting minor sources of atmospheric releases--further reducing potential operational releases.

In summary, potential releases from airborne or waterborne carry-off from contaminated surfaces are expected to be small. They can be further reduced to negligible levels by:

1. Continuing to maintain strict housekeeping procedures to maintain potential contamination of equipment and surfaces to levels as low as reasonably achievable.

2. Improvements in waste form and packaging.

3. Enforcement of existing transportation regulations.

4. Minor improvements in environmental monitoring.

6.2.2 Potential Public Impacts From Operational Accidents

During the operation of an LLW disposal facility, potential releases of radioactive material to the environment can also occur through onsite accidents. Such potential accidents could include: (1) the sudden and complete rupturing of a waste container on the site and subsequent release of a portion of the contained radioactivity or (2) a fire igniting on the site and consuming a number of waste packages, with subsequent release of a portion of the contained radioactivity in the waste.

The scenario involving the rupture of an individual waste container is differentiated from the earlier discussion regarding the potential for minor leaks and spills on the site. In this case, it can be postulated that a waste container is very badly ruptured, such as from dropping the waste container from some height, and a more significant quantity (compared with the earlier case) of radionuclides are available for transport by the air. The offsite airborne impacts from this potential accident would be acute (that is, impacts would occur over a short time period). The accident would also contaminate a portion of the ground surface. However, as discussed in Section 6.2.1, all disposal facilities currently have and will continue to have requirements in the license and written procedures for rapidly cleaning up the contaminated surface. Thus, potential offsite transport from rainwater washing away the contaminated ground surface would be minimal.

A fire potentially arising on the LLW disposal facility site can also result in acute (short-term) airborne releases, as well as contamination of some of the ground surface. Again, the impact of this accident would be principally from the offsite airborne releases. The fire could potentially occur on a transport vehicle or in a group of waste packages stored onsite or placed in the trench but not yet covered by earth).

The types and magnitudes of accidents potentially occurring at an LLW disposal facility are generally similar to those potentially occurring during transportation of LLW to the disposal site. Impacts from such potential accidents have been addressed by an environmental statement on the transportation of radioactive material by air and other modes (Ref. 4). In addition, NRC has recently published (in July 1980) a contractor's report providing an analysis of potential radioactive material transportation impacts in urban environments (Ref. 5).

Consequences from potential accidents are site specific and would already fall under existing NRC regulations in 10 CFR Part 20. Such consequences would be addressed as part of normal licensing reviews. However, it is useful to consider the potential consequences of operational accidents in this environmental impact statement to determine if such impacts can be potentially reduced on a generic basis. The principal variable which may be considered would be potential improvements in waste forms. These potential improvements in waste form and reduction in potential offsite impacts are considered below.

6.2.2.1 Analysis of Accidental Fire

The methodology for estimating potential impacts from the operational fire accident is described in Appendix G and Reference 6. For this scenario, a fire is assumed to break out in a disposal trench and involve about 50 m^3 of waste. This volume is estimated from an assumed volume of 200 m^3 of waste received daily at the disposal facility, which corresponds to about one million m^3 of waste over 20 years. Two disposal cells are assumed to be simultaneously in operation, and half of the waste in one of the disposal cells is subjected to the accidental fire scenario. (The other half is assumed to be covered with back fill.) The fire is assumed to last for two hours, which is conservative considering that a potential fire can easily be extinguished through covering with soil, and entrained radionuclides are all assumed to travel in one direction and result in exposures to an individual located at the facility boundary in the centerline of the contaminated plume.

In this environmental impact statement, no credit is given for reduction in airborne releases due to waste packaging--that is, metal waste containers such as liners or 55-gallon drums would tend to retard the spread of fires from one waste container to another. However, the propensity of each waste stream to burn is considered and incorporated into the calculations. Each of the 36 waste streams for each waste spectrum are rated according to their inability to burn and assigned a value for the flammability index (I4) as follows: (See Appendices D and G)

Flammability Index (I4)	Description
0	nonflammable
1	low-flammability (mixture of material with indices of 0 and 2)
2	burns if heat is applied but does not otherwise support burning
3	flammable (supports burning)

In the analysis, the use of the indices is determined by the operating practices at the disposal facility. If waste segregation is not practiced at the disposal facility (i.e., all waste streams are disposed randomly and mixed together), then the fraction of radioactivity released from each waste stream is given by the relationship $0.1 \times 20^{(I4-3)}$. By this, flammable waste streams (I4=3), are assumed to release the fraction 0.1 of the radioactivity within the waste packages involved in the fire. Other waste streams having flammability indices equal to 0, 1, or 2 would not ordinarily burn by themselves. However, because these streams are assumed to be involved in the fire, a fractional release is assumed for each stream which is a function of the value of I4 for the stream. An exception is activated metals, which are always assumed to have a fractional release equal to zero.

If waste segregation is practiced (i.e., combustible material is separated and disposed in a segregated manner from other waste streams), then only the combustible material would be involved in the fire. In this case, the fractional release from the flammable waste streams would still be equal to 0.1 but the fractional releases from the other waste streams (I4 = 0, 1, or 2) would be equal to zero.

The impacts from a potential accidental fire are shown in Table 6.3. Table 6.3 summarizes the impacts calculated from each of the 36 waste streams, assuming 50 m^3 of each waste stream is involved in a fire. This is done to compare the relative impacts of each waste stream from one spectrum to the next. Also shown in Table 6.3 is a volume-weighted average of impacts from all waste streams. This is numerically equivalent to the assumption that of the 50 m^3 of waste assumed to be involved in the fire, the amount of each waste stream involved in the fire is proportional to the fractional volume of each waste stream delivered to the disposal facility. It is used as a "hazard index" for fires at the disposal facility.

As shown in Table 6.3, the practice of waste segregation would tend to reduce the overall potential hazard from an accidental fire. As can be seen, the volume weighted impacts for Case 1 are about 5.5 mrem to the whole body and 32 mrem to the lung. However, in Case 4A, in which waste segregation is practiced at the disposal facility, volume-weighted whole body and lung exposures are reduced to 3.9 and 18.7 mrem, respectively. In Case 1, as in all cases, the releases from activated metals (P-NCTRASH, B-NCTRASH, F-NCTRASH, LNFRCOMP, and N-HIGHACT) are taken to be essentially zero. In addition, since neither the N-SOURCES or the L-DECONRS streams are classified as being suitable for near-surface disposal, the impact from these two streams is also zero.

Waste spectrum 1 was assumed for both Cases 1 and 4A. However, waste spectrum 2 was assumed for Case 7A while waste spectrum 3 was assumed for Case 8. In waste spectrum 2, prior to delivery to the disposal facility, compressible waste streams such as P-COTRASH or I-COTRASH are assumed to be processed by compaction at the waste generator while the I+COTRASH, N+SSTRASH, and N+COTRASH are assumed to be processed by an improved compactor/shredder at a regional processing center. As shown in Case 7A, therefore, estimated impacts from the accidental fire are increased (due to increased radionuclide concentrations) for the waste streams subject to processing. As a result, overall volume-weighted impacts are increased relative to the preceeding two cases.

This may be a considerable overestimate, however. Although compaction increases the concentration of radionuclides in the packaged wastes, it also produces a waste form which is apt to burn at a slower rate. This would be expected to reduce the fraction of radionuclides released into air.

Table 6.3 Stream-by-Stream Impacts to the Whole Body and Bone from an Accidental Fire (mrem)

	Case 1 (WS1)*		Case 4A (WS1)		Case 7A (WS2)		Case 8 (WS3)	
Stream	Body	Lung	Body	Lung	Body	Lung	Body	Lung
P-IXRESIN	5.712E-01	3.058E+00	0.	0.	0.	0.	0.	0.
P-CONCLIQ	6.135E-02	5.102E-01	0.	0.	0.	0.	0.	0.
P-FSLUDGE	8.200E-01	7.780E+00	0.	0.	0.	0.	0.	0.
P-FCARTRG	2.829E+01	2.860E+02	0.	0.	0.	0.	0.	0.
B-IXRESIN	4.451E+01	3.968E+02	0.	0.	0.	0.	0.	0.
B-CONCLIQ	1.998E-01	1.617E+00	0.	0.	0.	0.	0.	0.
B-FSLUDGE	3.139E+00	3.085E+01	0.	0.	0.	0.	0.	0.
P-COTRASH	7.042E+00	6.561E+01	7.042E+00	6.561+01	1.408E+01	1.312E+02	0.	0.
P-NCTRASH	0.	0.	0.	0.	0.	0.	0.	0.
B-COTRASH	5.507E+00	5.228E+01	5.507E+00	5.228E+01	1.101E+01	1.046E+02	0.	0.
B-NCTRASH	0.	0.	0.	0.	0.	0.	0.	0.
F-COTRASH	1.810E-03	3.238E+00	1.810E-03	3.238E+00	2.715E-03	4.857E+00	0.	0.
F-NCTRASH	0.	0.	0.	0.	0.	0.	0.	0.
I-COTRASH	1.175E+01	5.086E+01	1.175E+01	5.086E+01	2.349E+01	1.017E+02	0.	0.
I+COTRASH	1.175E+01	5.086E+01	1.175E+01	5.086E+01	4.698E+01	2.034E+02	0.	0.
N-SSTRASH	1.810E-04	3.238E-01	0.	0.	0.	0.	0.	0.
N+SSTRASH	1.810E-04	3.238E-01	0.	0.	0.	0.	0.	0.
N-LOTRASH	3.670E+00	1.589E+01	3.670E+00	1.589E+01	7.340E+00	3.179E+01	0.	0.
N+LOTRASH	3.670E+00	1.589E+01	3.670E+00	1.589E+01	1.468E+01	6.357E+01	0.	0.
F-PROCESS	4.396E-06	7.863E-03	0.	0.	0.	0.	0.	0.
U-PROCESS	1.489E-05	2.725E-02	0.	0.	0.	0.	0.	0.
I-LQSCNVL	6.399E+00	5.285E-02	6.399E+00	5.285E-02	8.191E+00	6.765E-02	0.	0.
I+LQSCNVL	6.399E+00	5.285E-02	6.399E+00	5.285E-02	6.399E+00	5.285E-02	6.399E+00	5.285E-02
I-ABSLIQD	1.127E+01	5.047E+01	1.127E+01	5.047E+01	2.050E+01	9.177E+01	0.	0.
I+ABSLIQD	1.127E+01	5.047E+01	1.127E+01	5.047E+01	1.127E+01	5.047E+01	1.127E+01	5.047E+01
I-BIOWAST	1.024E+00	5.237E-01	0.	0.	0.	0.	0.	0.
I+BIOWAST	1.024E+00	5.237E-01	0.	0.	0.	0.	0.	0.
N-SSWASTE	8.800E-06	1.574E-02	0.	0.	0.	0.	0.	0.
N-LOWASTE	6.519E+00	7.200E+00	6.519E+00	7.200E+00	6.519E+00	7.200E+00	6.519E+00	7.200E+00
L-NFRCOMP	0.	0.	0.	0.	0.	0.	0.	0.
L-DECONRS	0.	0.	0.	0.	0.	0.	0.	0.
N-ISOPROD	5.480E+01	1.937E+00	0.	0.	0.	0.	0.	0.
N-HIGHACT	0.	0.	0.	0.	0.	0.	0.	0.
N-TRITIUM	5.338E+02	5.338E+02	5.338E+02	5.338E+02	5.338E+02	5.338E+02	5.338E+02	5.338E+02
N-SOURCES	0.	0.	0.	0.	0.	0.	0.	0.
N-TARGETS	2.303E-03	2.303E-03	0.	0.	0.	0.	0.	0.
Volume-Weighted Impacts	5.470E+0	3.208E+1	3.875E+0	1.868E+1	5.894E+0	2.841E+1	2.387E+0	2.219E+0

In waste spectrum 3 (Case 8), most of the compressible waste streams are incinerated and the ashes solidified. As a result, these waste streams are convented into a nonflammable form. Volume-weighted impacts to body and bone are reduced to 2.4 mrem and 2.2 mrem, respectively.

6.2.2.2 Analysis of Dropped Container

The methodology for estimating potential impacts from the dropped-container operational accident scenario is described in Appendix G and Reference 6. For this scenario, a waste container is assumed to be dropped from a significant height so that the waste container breaks open and a portion of the radioactive contents of the package is released into the air where it is transported offsite and leads to subsequent human exposure. Potential releases are modeled as a "puff", and resulting human exposure would occur over a short time period. The potential exposures from this scenario are a strong function of the form of the waste delivered to the disposal facility--i.e., improved, less dispersible waste forms lead to lower potential releases and reduced potential human exposures.

In a similar manner to Section 6.2.2.1, impacts are first calculated for an equal volume of each of the 34 waste streams delivered to the disposal facility. (The N-SOURCES and L-DECONRS streams are excluded.) This allows comparison of the relative impacts of each waste stream from one spectrum to the next. Then, a volume-weighted average of impacts from all waste streams delivered to the disposal facility is calculated. This can be again envisioned as a "hazard index" for a dropped container accident at the diposal facility. Calculation of impacts is complicated by the fact that wastes are delivered to the disposal facility in a variety of container sizes--from 55-gallon drums to large wooden boxes to large carbon-steel liners. To calculate impacts, some simplifying assumptions must be made. This is acceptable with the understanding that the main purpose of this analysis is to compare the relative hazard of different waste forms.

The container size, therefore, is assumed to be 4.8 m^3 (170 ft^3), which is the size of a typical resin liner. This size is reasonable for many high activity waste streams (such as resins and filter media) but is a considerable overestimate for wastes packaged in 55-gallon drums (.21 m^3) but much less of an overestimate for wastes packaged in large wooden boxes (e.g., a 4' x 4' x 8' box has a volume of 128 ft^3, or 3.63 m^3).

Unsolidified waste streams such as trash are assumed to have a fractional release equal to 0.001. This value is believed to be very conservative and is the same as the dispersible fraction applied to dispersion of powdered PuO_2 from waste packages involved in transportation accidents (Ref. 6). However, this fractional release is multiplied by a factor which accounts for the relative dispersibility of improved waste forms. This factor is determined by the leachability index$^{(I6)}$ and is given as $10^{(1-I6)}$. Values calculated for this factor as a function of I6 are given as follows:

I6	Waste Form	$10^{(1-I6)}$
1	no solidification	1
2	solidification in half cement and half urea-formaldehyde	0.1
3	solidification in half cement and half synthetic polymer	0.01
4	solidification in 100% synthetic polymer	0.001

The property values for this comparative dispersibility are based upon consideration of comparative mechanical strengths (compressive, unnotched Izod impact, and fragmentation tests) measured for the waste forms (Ref. 7). Again, the dispersion from activated metals is assumed to be negligible.

Upon release from the waste packages, the entrained radioactive particles are conservatively assumed to travel in one direction and result in exposures to an individual located at the facility boundary in the centerline of the contaminated plume.

The calculated impacts are given in Table 6.4 for waste spectra 1 through 3. The improvement in relative impacts is significant from one spectrum to the next. Comparing Case 1 (waste spectrum 1) with Case 7A (waste spectrum 2), relative impacts associated with LWR process wastes (P-IXRESIN to B-FSLUDGE streams) are considerably reduced. A further reduction in relative impacts is seen for Case 8 (waste spectrum 3).

For some streams, such as P-COTRASH and N-LOTRASH, relative impacts are raised for waste spectrum 2 but drop to lower levels (than waste spectrum 1) for waste spectrum 3. This is because in waste spectrum 2, such waste streams are compacted and the resulting radionuclide concentrations are raised. However in waste spectrum 3, these waste streams are incinerated and solidified in a synthetic polymer. Although radionuclide concentrations are raised, the improved solidified waste form results in lowered releases and lowered relative impacts. (Compacting the waste (as in waste Spectrum 2) would also be expected to result in a form which is less readily dispersible. This consideration, however, was not included in the calculations.)

As can be seen, the total volume weighted impacts are 1.8 mrem whole body and 16.8 to the lung for Case 1. However, these drop for Case 7A by respective factors of 12 and 17 to .15 mrem whole body and 1 mrem to the lung. For Case 8, volume weighted impacts to whole body and lung are further reduced (by additional factors of 2.5 and 3) to .058 mrem and .033 mrem, respectively. Clearly, a large improvement in relative hazard is shown for waste spectrum 2 (where all sludges and filter media are solidified) over waste spectrum 1 (where sludges

Table 6.4 Stream-by-Stream Impacts to Whole Body and Lung from Dropped-Container Accident (mrem)

	Case 1 (WS1)*		Case 7A (WS2)		Case 8 (WS3)	
Stream	Body	Lung	Body	Lung	Body	Lung
P-IXRESIN	2.075E-01	1.110E+00	1.257E-03	6.730E-03	1.037E-04	5.552E-04
P-CONCLIQ	4.456E-02	3.706E-01	2.056E-02	1.710E-01	1.871E-03	1.556E-02
P-FSLUDGE	5.956E+00	5.651E+01	3.610E-02	3.425E-01	2.978E-03	2.826E-02
P-FCARTRG	1.027E+01	1.039E+02	1.027E-01	1.039E+00	1.027E-02	1.039E-01
B-IXRESIN	1.617E+01	1.441E+02	9.798E-02	8.734E-01	8.083E-03	7.206E-02
B-CONCLIQ	1.452E-01	1.175E+00	3.126E-02	2.530E-01	2.439E-03	1.974E-02
B-FSLUDGE	2.280E+01	2.241E+02	1.382E-01	1.358E+00	1.140E-02	1.120E-01
P-COTRASH	1.279E-01	1.191E+00	2.557E-01	2.383E+00	5.115E-03	4.766E-02
P-NCTRASH	0.	0.	0.	0.	0.	0.
B-COTRASH	1.000E-01	9.494E-01	2.000E-01	1.899E+00	4.000E-03	3.798E-02
B-NCTRASH	0.	0.	0.	0.	0.	0.
F-COTRASH	3.287E-05	5.879E-02	4.930E-05	8.819E-02	6.574E-07	1.176E-03
F-NCTRASH	0.	0.	0.	0.	0.	0.
I-COTRASH	2.133E-01	9.235E-01	4.266E-01	1.847E+00	2.129E-03	9.231E-03
I+COTRASH	2.133E-01	9.235E-01	8.531E-01	3.694E+00	8.517E-03	3.692E-02
N-SSTRASH	6.574E-05	1.176E-01	9.860E-05	1.764E-01	3.287E-07	5.879E-04
N+SSTRASH	6.574E-05	1.176E-01	1.972E-04	3.528E-01	1.315E-06	2.352E-03
N-LOTRASH	6.664E-02	2.886E-01	1.333E-01	5.772E-01	6.652E-04	2.885E-03
N+LOTRASH	6.664E-02	2.886E-01	2.666E-01	1.154E+00	2.661E-03	1.154E-02
F-PROCESS	6.386E-04	1.142E+00	6.386E-04	1.142E+00	6.386E-04	1.142E+00
U-PROCESS	2.163E-03	3.958E+00	2.163E-03	3.958E+00	2.163E-03	3.958E+00
I-LQSCNVL	1.162E-01	9.597E-04	1.487E-01	1.228E-03	7.878E-04	6.460E-06
I+LQSCNVL	1.162E-01	9.597E-04	1.162E-01	9.597E-04	1.162E-01	9.597E-04
I-ABSLIQD	2.047E-01	9.165E-01	3.722E-03	1.666E-02	3.071E-04	1.375E-03
I+ABSLIQD	2.047E-01	9.165E-01	2.047E-01	9.165E-01	2.047E-01	9.165E-01
I-BIOWAST	3.720E-01	1.902E-01	3.720E-01	1.902E-01	5.351E-03	2.733E-03
I+BIOWAST	3.720E-01	1.902E-01	3.720E-01	1.902E-01	3.720E-01	1.902E-01
N-SSWASTE	1.278E-03	2.286E+00	1.278E-03	2.286E+00	1.278E-03	2.286E+00
N-LOWASTE	1.184E-01	1.307E-01	1.184E-01	1.307E-01	1.184E-01	1.307E-01
L-NFRCOMP	0.	0.	0.	0.	0.	0.
L-DECONRS	0.	0.	0.	0.	0.	0.
N-ISOPROD	3.980E+00	1.407E-01	2.587E-01	9.146E-03	2.587E-01	9.146E-03
N-HIGHACT	0.	0.	0.	0.	0.	0
N-TRITIUM	9.694E+00	9.694E+00	9.694E+00	9.694E+00	9.694E+00	9.694E+00
N-SOURCES	0.	0.	0.	0.	0.	0.
N-TARGETS	3.345E-01	3.345E-01	3.345E-01	3.345E-01	3.345E-01	3.345E-01
Volume-Weighted Impacts	1.783E+0	1.676E+1	1.460E-1	9.680E-1	5.791E-2	3.288E-1

*Waste spectrum 1

and filter media are assumed to be dewatered). A much smaller improvement is seen for waste spectrum 3 (incorporating further improved waste forms) relative to waste spectrum 2.

High integrity containers (HICs) have not been specifically analyzed in this environmental impact statement for their behavior under accident conditions. However, to perform their function, HICs would be expected to be constructed in a more robust manner than ordinary waste containers such as carbon steel liners. Therefore, the potential hazard from operational accidents for wastes (such as dewatered resins) packaged in HICs would also be expected to be reduced.

6.2.2.3 Summary

The preceeding analysis examined the relative hazard from operational accidents at a disposal facility involving either (1) a potential fire in a disposal cell or (2) a potential dropped container which breaks open and disperses a portion of its contents into the air. In general, it was determined that actions that have previously been determined to reduce potential long-term impacts from ground-water migration or inadvertent human intrusion also reduced short-term impacts from potential accidents. For example, segregation of compressible, easily degradable waste streams from stable waste streams reduces intruder impacts, ground-water impacts, and long-term care costs. Since most of these compressible waste forms are also flammable, waste segregation is also seen to reduce potential impacts from an accidental operational fire.

As another example, use of improved waste forms or high integrity containers were also shown to reduce intruder impacts, ground-water impacts, and long-term costs. Improved waste forms and high integrity containers would also act to reduce impacts from an accidentally dropped container.

6.3 OCCUPATIONAL EXPOSURES

Occupational exposures would occur through normal operations in the surveying of incoming packages and transport vehicles and in unloading and waste emplacement operations. Limits for occupational exposures have already been established in the existing regulation 10 CFR Part 20. Past history at the existing burial sites has shown that occupational exposures have been within the existing guidance for such exposures in 10 CFR Part 20. Licensee programs to minimize exposures are routinely analyzed as part of normal licensing actions at existing disposal facilities. The occupational exposures received based on analysis of the base case facility and alternatives considered have been previously summarized in Chapters 4 and 5.

6.4 PERFORMANCE OBJECTIVE

The NRC regulation, 10 CFR 20, already provides standards for control of and limitations for release of radioactive materials to the environment from operations of NRC-licensed facilities, as well as limitations on the allowable radiation doses to radiation workers and the public.

Limits in Part 20 for potential exposures to individuals in unrestricted areas are 0.5 rem (500 mrem) per year to the whole body of individuals in unrestricted areas. The regulation also provides in Appendix B, Table II, a table of maximum permissible concentrations (MPCs) of radionuclides in air or water from releases to unrestricted areas. These MPC values are based upon a maximum potential whole body dose commitment to an individual of 500 mrem/year. Limits for other organs include 500 mrem/year to blood forming organs, 3000 mrem/year to bone surfaces, and 1500 mrem/yr to other organs except thyroid. For thyroid, a limit of 3000 mrem/yr was used except for exposures from radioiodine, for which a limit of 1500 mrem/yr to a childs thyroid was used. Also contained in the regulation is a requirement that potential exposures to individuals and populations should be maintained to levels as low as reasonably achievable (ALARA). In practice releases to unrestricted areas and potential exposures from NRC and Agreement State licenses are maintained well below the 500 mrem/year limit.

For normal operations of a disposal facility, therefore, standards in 10 CFR Part 20 already exist and are already being applied. Facility compliance with this standard is already routinely assessed as part of normal licensing procedures.

6.5 DEVELOPMENT OF TECHNICAL CRITERIA

As discussed in Section 6.4, the proposed performance objective for potential offsite and occupational impacts during operation of the disposal facility is to continue to apply the radiological health and safety requirements in the existing regulation 10 CFR Part 20. In applying this performance objective to existing and future disposal facilities, one alternative approach would be to set out in 10 CFR Part 61 a number of prescriptive requirements for safe operation of disposal facilities. However, NRC staff believes that this alternative can lead to a number of practical difficulties. For example, measures which could be used to minimize potential operational releases will be influenced by site-specific conditions at the particular disposal facility site considered. More importantly, detailed prescriptive requirements would inhibit incorporation of potential improvements in site safety.

6.5.1 Licensing Review of Applicants Operational Health and Safety Program

Based upon past NRC licensing staff experience, a licensee's operational procedures and programs for compliance with the operational safety performance objective would be evaluated on a case-by-case basis. Each applicant for a license would be required to establish and implement such programs and would be required to describe such programs in detail in his license application. The acceptability of each licensee's operational procedures and programs would be evaluated as a part of the licensing process on a case-by-case basis considering the nature and scope of the operations to be conducted at the disposal facility. Following this evaluation and as a part of the licensing of a disposal facility, the licensee would be required to formally compile the final procedures into a site operations manual that would be utilized by the licensee for operation of the facility. Any subsequent and significant changes to the manual would be subject to NRC review.

The nature, details and costs of representative procedures and programs have been included in Appendix E as a part of the description of a typical disposal facility. The costs and impacts of these programs have been included in the analyses of the base case typical facility. Some of the procedures and programs which would be analyzed as part of a specific application would include the following:

- The applicant's radiation safety program for control and monitoring of radioactive effluents and occupational radiation exposure to demonstrate compliance with the Part 20 requirements and to control contamination of disposal facility personnel, vehicles, equipment, buildings, and the grounds. Both routine operations and accidents would be addressed, and the program description would include procedures, instrumentation, facilities, and equipment.

- The applicant's quality assurance program for siting, design, construction, and operation of the disposal facility, and the receipt, handling, and emplacement of waste. Audits and managerial controls would be included as part of this program.

- The applicant's procedures and plans for construction and operation of the disposal facility. These would include methods of construction; waste emplacement; procedures for and areas of waste segregation; types of intruder barriers; onsite traffic and drainage systems; methods and areas of waste storage; and methods to control surface water and ground-water access to the wastes.

- The applicant's environmental monitoring program to provide data to evaluate potential health and environmental impacts, as well as plans for taking corrective measures if migration of radionuclides is indicated.

- The applicant's administration procedures to control activities.

- The applicant's physical security measures.

- If the application includes the proposed receipt, possession, and disposal of special nuclear material, the procedures and provisions for criticality control.

6.5.2 Minimum Waste Form and Packaging Requirements

There are still a number of technical requirements that can be applied to waste form and packaging which will help to further improve operational safety. The analyses in Section 6.2 indicated that placing the higher activity waste streams such as ion exchange resins into a less dispersible waste form acts to improve operational safety. This can be accomplished by such techniques as waste solidification or use of high integrity containers. However, wastes delivered to disposal facilities are composed of a variety of forms and radionuclides contained in these wastes may vary over a wide range.

Over the years, a number of general waste form and packaging requirements have been developed and applied at disposal facilities to provide protection of the health and safety of site workers, to facilitate handling of waste, and to minimize the potential for releases to offsite areas. These requirements have been condensed from consideration of current practice at existing disposal facilities. These requirements have also been included as a part of the base case facility description and the costs and impacts are reflected in the costs and impacts of the base case. They are discussed in further detail below. These requirements are thus a codification of existing practice and include:

1. Requirement - The waste form and packaging must meet all applicable transportation requirements of the Commission as set forth in 10 CFR Part 71 and of the Department of Transportation (DOT) as set forth in 49 CFR Parts 171-179. Wastes, however, shall not be packaged for disposal in cardboard, fiberboard, or other paper packages. Wastes shall also not be in a liquid form or contain liquid exceeding 1% of the waste volume. Absorbants may be used for immobilization of liquid waste, provided that sufficient absorbant material is used to absorb twice the volume of liquid. Liquid scintillation fluids and other liquids and radioactive materials in individual units or vials used for clinical or laboratory testing may be packaged and disposed of provided the units or vials are packaged in sufficient absorbant material to absorb twice the total volume of liquid contained in the units or vials.

Analysis: The minimum requirements on waste form and packaging set out in DOT and NRC regulations for transportation are of primary importance with respect to the handling of the waste during storage, transportation and disposal. If package integrity is maintained during emplacement within disposal cells, the package can also provide an initial barrier to the release of package contents after disposal. Separate requirements on the packaging of waste could be established based on individual requirements for storage, transportation and disposal. For most wastes and for the normal and accident conditions encountered during storage, transportation and disposal, NRC believes the requirements imposed for safety in transportation are adequate and no additional requirements are needed. (In some cases, overpacks are also used to provide additional shielding during transportation.) NRC believes, however, that the use of cardboard or paper packages should be discontinued because they can easily rupture, contaminating waste transport vehicles and site surfaces, as well as increase occupational exposures. In the past, there have been several instances where cardboard or fibreboard containers have been improperly stacked during transportation and have been cracked by heavier wastes packages, thus contaminating the waste transport vehicle. In addition, cardboard or paper packages may readily compress after disposal. For some wastes, however (e.g., large quantities of very mobile nuclides such as tritium), the use of specially designed containers that would retard the release of package contents after disposal, allowing for decay, should be considered and used. NRC plans to review these on a case-by-case basis.

The disposal of bulk quantities of liquid waste should not be allowed because of the increased potential for more rapid migration and the demonstrated increased potential for contamination of facility ground and equipment. Liquids, however, cannot be economically totally excluded from wastes, and NRC is applying a limit of 1% of the volume of the waste as a "free liquid requirement." NRC considered elimination of the use of absorbent material for liquid wastes but recognizes that certain types of liquids (e.g., organic solvents and oils) are quite difficult to solidify at this time. The use of absorbent materials should be allowed to continue for the low activity wastes until better processes for solidification or alternatives such as incineration are available.

No incremental cost/benefit evaluation for this requirement has been conducted since it reflects current practice. The costs and impacts have been included and analyzed as a part of the base case.

2. Requirement - Only radioactive waste shall be accepted for disposal at a near-surface disposal facility. Waste shall not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or which reacts explosively with water. Waste shall not contain, or be capable of generating, appreciable quantities of toxic gases, vapors, or fumes. Pyrophoric materials contained in wastes shall be treated, prepared and packaged to be nonflammable.

   Wastes in a gaseous form shall be packaged at a pressure not to exceed one atmosphere at normal temperatures, and wastes containing biological, pathogenic, or infectious material shall be treated to reduce the potential hazard.

Analysis: These requirements are principally directed at health and safety considerations involved in the handling and placement of wastes in disposal trenches. Combustion, detonation, or excessive reaction of the waste at normal temperatures and pressures can lead to increased occupational exposures and releases of radioactive and toxic materials from the site. These materials, after disposal, can also accelerate migration of radionuclides through interaction with other wastes. The alternative of combined disposal of such wastes and other types of chemically hazardous waste with radioactive waste at a near-surface disposal facility was not considered a viable alternative.

No incremental cost/benefit analysis has been conducted for these requirements since they reflect current practice. They are currently being followed at the existing sites and the costs and impacts have been included in the base case analysis.

6.6 EFFLUENTS DUE TO WASTE PROCESSNG AT A REGIONAL PROCESSING CENTER (ASSUMED TO BE LOCATED AT THE DISPOSAL FACILITY)

As previously discussed, one of the viable options addressed in preceeding sections in this environmental impact statement was that of processing of waste on a regional basis at a central processing facility. Such a facility could be located at or separately from the disposal facility. Such central waste processing activities involves safety considerations separate from and beyond the purview of those involving the receipt, handling, and disposal of waste at a disposal facility to be addressed in Part 61. In addition to occupational safety and other considerations at such a facility, such waste processing activities can lead to potential airborne releases of radionuclides and subsequent exposures to the public in the neighborhood of the regional processing facilities. NRC analyzed the potential population exposures due to the assumed operation of a central waste processing facility (an incinerator) which was colocated with the disposal facility. These exposures were estimated to be approximately 1.87 man-rem/year, arising from the assumed incineration of 100,000 m^3 of combustible trash per year. The total population assumed to be exposed was 480,000 within a 50-mile radius of the processing facility. (Also see Section 5.2.4.5 for further information.)

With respect to such potential exposures, a limiting criteria for such central waste processing operations should be considered. Such limiting criteria may perhaps best be developed by consideration of existing standards.

For example, effluents from nuclear power plants are limited to levels prescribed in 10 CFR Part 50, Appendix I. In addition, effluent limits for nuclear power operations have been established by EPA in 40 CFR 190. This regulation provides environmental radiation dose standards for operations which are part of the uranium fuel cycle. Specifically excluded from this regulation are uranium mining operations, operations at waste disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered non-uranium special nuclear and byproduct materials from the fuel cycle. The regulations provide limits for annual allowable doses to persons in the general environment (that is, 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public) as well as limitations for annual allowable releases of certain radionuclides (that is, Kr-85, I-129, and Pu-239).

A rule change to 10 CFR Part 20 formally incorporating the requirements in 40 CFR 190 into Part 20 was recently proposed by NRC (Ref. 8). The 40 CFR 190 limits, however, are being implemented by NRC staff in specific licensing actions.

Limits for airborne radionuclide releases in the range of 40 CFR 190 have also been extended to other licensing actions by NRC licensing staff. For example, NRC licensing staff have applied general limits in the range of 40 CFR 190--i.e., approximately 1/10 of 10 CFR Part 20 standards--for small institutional radioactive waste incinerators.

It would therefore appear that if waste processing activities were to take place at a central waste processing facility, an effluent limitation criteria incorporating the release limits of 40 CFR 190 would appear to be appropriate.

If extensive waste processing were carried out at a fuel cycle facility, the limits of 40 CFR 190 would be applied as part of existing standards. With respect to waste processing carried out at nonfuel cycle facilities, NRC licensing staff is already applying use of 1/10 of Part 20, Table II values as an objective. The processing of waste can either take place at the point of waste generation or at a central facility. If the processing does take place at a central facility, it is logical to expect that the same limits that would apply at the point of generation should also be applied. In this case the lower limits established by 40 CFR 190 should be applied to population exposures from waste processing operations at an central processing facility. These annual limits are:

- o 25 mrem (whole body);
- o 75 mrem (thyroid);
- o 25 mrem (any other organ).

From the previous analysis, it is expected that these limits would be readily met at any such central waste processing facility.

REFERENCES

1. Mooney, R. R., Environmental Radiation Surveillance in Washington State, Seventeenth Annual Report: July 1977-June 1978, State of Washington Department of Social and Health Services, Olympia, Washington, 1979.

2. U. S. Energy Research and Development Administration, Final Environmental Statement: Waste Management Operations (For) Hanford Reservation, Richland, Washington, ERDA-1538, October 1975.

3. Chem-Nuclear Systems, Inc., Environmental Assessment for Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, January 1980.

4. U.S. Nuclear Regulatory Commission, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, December 1977.

5. U.S. Nuclear Regulatory Commission, Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment, NUREG/CR-1074, July 1980.

6. Oztunali, O. I., G. Re; and C. J. Pitt, Data Base for Radioactive Waste Management, Volume 4: Impacts Analysis Methodology Report, NUREG/CR-1759, Dames & Moore for NRC, to be published.

7. Oztunali, O. I., et al., Data Base for Radioactive Waste Management, Volume 2: Waste Source Options Report, NUREG/CR-1759, Dames & Moore for NRC, to be published.

8. U. S. Nuclear Regulatory Commission, Proposed Rule: Environmental Protection Standards for Nuclear Power Operation, Federal Register, 45 FR 26072, April 17, 1980.

Chapter 7

WASTE CLASSIFICATION

7.1 INTRODUCTION

Radioactive waste classification is the culmination of the Part 61 rulemaking effort. First as part of the Part 61 rulemaking effort, overall performance objectives for near-surface disposal were developed. The analysis and rationale for arriving at these performance objectives are set out in Chapters 4, 5, and 6 of this environmental impact statement. Based on the overall performance objectives, a number of technical requirements were developed, including requirements for institutional controls, waste form and packaging, disposal facility siting, and disposal facility design and operation. Waste classification is the mechanism that helps assure that the overall performance objectives will be met over the long term through the collective reflection of the technical requirements and controls established for near-surface radioactive waste disposal. To a waste generator, it establishes requirements on the form and content of waste and establishes how he should treat and package particular wastes. To a waste disposal facility operator, it defines the requirements and controls he should use in the disposal of particular wastes.

Earlier work to develop a waste classification methodology and system has been described in Chapter 2 of this environmental impact statement. This work, which is reported in References 1, 2, and 3 developed the concept that radioactive wastes should be classified based upon their potential hazard following disposal. As part of this work, an omnibus classification system was proposed based upon not exceeding generic radiation exposure limits which defined safe disposal. For example, in NUREG-0456 (Ref. 2), safe disposal is first defined as a potential exposure limit of 500 mrem/yr to the critical organ. Then, classes of waste were determined based upon calculation of maximum concentrations of radionuclides so as not to exceed these overall exposure limits through various exposure pathways.

In NUREG-0456, the classification system involves three types of actions in handling radioactive waste:

1. Discharge directly to the biosphere similar to handling routine trash.

2. Confine the waste for a period of time in a controlled manner with predictably low release rates.

3. Isolate the waste from the biosphere so that biologically significant releases or inadvertent reentry by mankind into the disposal area is highly unlikely.

In practice, this was modeled (and concentration limits were calculated based upon the assumed exposure limit) as:

1. Disposal into a sanitary landfill;

2. Disposal into a shallow land burial facility;

3. Disposal into a geologic repository.

In this work, the concept of disposal of waste at greater depths (deeper burial) was briefly discussed. This was expanded in a later work, NUREG/CR-1005, in which two more classes of waste were added based upon deeper burial (Ref. 3).

Based upon this work, NRC at one time considered developing a waste classification regulation as a separate rulemaking effort from the Part 61 regulation for low-level waste disposal. That is, an omnibus classification system would have been developed which would initially establish two classes of waste--one suitable for "de minimus" disposal and one for shallow land burial, with a third class of waste which would require disposal into a geologic repository. At the same time, the Part 61 regulation would develop requirements for shallow land burial. Subsequent rulemaking efforts would develop requirements and classification limits for disposal by other methods such as deeper burial or use of engineered structures.

NRC recognized, however, that such an omnibus classification system could have practical difficulties in that waste classification could not be developed independently of other requirements for waste disposal such as those for waste form and packaging. Therefore, the waste classification regulatory development effort was combined with that of the Part 61 regulatory effort. In addition, the Part 61 regulation was expanded to become an "umbrella" regulation under which a number of potential near-surface disposal techniques may be licensed.

Development of waste classification in terms of disposal requirements rather than an omnibus system is also of more practical use in determining types of wastes for which disposal should be of no regulatory concern. As observed by the Federal Radiation Policy Council (Ref. 4), an omnibus "de minimis" classification system would be likely to be so conservatively abstract as to be unworkable. In accordance with this policy, exemptions to Part 61 requirements are being handled on a specific waste stream basis. Analyzing specific waste stream exemptions on a case-by-case basis allows full consideration of the costs and benefits of such exemptions on a basis of need.

NRC has already followed this approach in establishing a new paragraph 20.306 to 10 CFR Part 20. This rule change exempts tritium and carbon-14 from disposal as radioactive waste when contained in liquid scintillation cocktail and animal carcass waste and not exceeding a concentration of .05 uCi/gm. Other waste streams may also readily lend themselves to treatment in this manner. An example would be very low activity residues from fuel fabrication operations or PWR secondary side resins.

7.1.1 Alternatives Considered

There are two principal alternatives that can be applied to classify waste for disposal:

1. Handle classification on a site-specific case-by-case basis; or

2. Develop a system that can be uniformly applied to all disposal facilities.

The actual impacts of near-surface disposal are site-specific and it could be possible to assure that the performance objectives and technical criteria are met at any site accepting all wastes by enforcing the Part 61 requirements at such a site on a case-by-case basis. The classification of waste would then be determined by site-specific conditions and considerations, and each site would have its own unique controls for particular wastes. However, it is difficult to regulate in this manner. Although the NRC staff believes that some flexibility to account for site-specific conditions needs to be included in the classification system, such flexibility could be very confusing to all parties concerned if carried to extremes. For example, waste generators could be faced with an extreme range in requirements and controls based on the particular site related requirements for disposal.

What is needed is a generic nonsite-specific classification system which can be uniformly applied by waste generators and disposal facility operators. The most convenient system to implement would be one in which actions are triggered by radionuclide quantity or concentration levels in waste streams. This would be more convenient to both regulators and licensees. Any waste generator, once the concentration or quantity of radionuclides in a particular waste stream is known, can then key the waste stream for a particular action at a disposal facility. Once the keyed waste stream arrives at the disposal site, the disposal facility operator can then carry out and exercise the appropriate controls for disposal.

7.1.2 Development of Waste Classes

Based upon the work in Chapters 4 and 5, there are two fundamental mechanisms to classify wastes for long-term hazard:

1. Consideration of potential hazard to an inadvertent intruder due to direct contact with the disposed waste; and

2. Consideration of potential hazard to an individual or a population from potential consumption or use of contaminated ground water.

From the analysis in Chapter 4, three general classes of waste have been determined and used in the analysis in Chapter 5:

A. Wastes for which there are no stability requirements but which should be disposed in a segregated manner from other wastes. The upper limit for these wastes is determined based upon a limit of 500 mrem/yr (whole body) to a potential intruder as calculated at the end of 100 years of institutional active control using the most restrictive limit from either the intruder-construction scenario or the intruder-agriculture scenario.

B. Wastes which need to be placed in a stable form and disposed in a segregated manner from unstable waste forms. Stability may be achieved through use of a solid waste form, packaging in a structurally stable container, or use of stabilization measures at a disposal facility. The upper limit for these wastes is determined based upon a limit of 500 mrem/yr (whole body) to a potential intruder as calculated at the end of 100 years of active institutional control using an intruder-discovery scenario.

C. Wastes which need to be placed into a stable form, disposed in a segregated manner from unstable waste forms and disposed of so that a barrier is provided against potential inadvertent intrusion. One type of acceptable barrier would be layering, covering the waste with a minimum of 5 meters of earth and lower activity wastes. An upper limit for these wastes is determined based upon a limit of 500 mrem/yr (whole body) to a potential intruder as calculated at 500 years from the beginning of the active institutional control period using the most restrictive limit from either the intruder-construction scenario or the intruder-agriculture scenario. (The barrier is assumed to be effective for only 500 years).

Wastes which exceed the upper limit as calculated by item C. above would normally be considered unacceptable for near-surface disposal. Wastes containing higher activities would be potentially allowed on a case-by-case basis depending upon specific waste forms and disposal methods. Such special consideration would be most applicable to wastes having radionuclides of moderate half lives (e.g., about 30-100 years).

In addition, two general classes of waste were developed in Chapter 5, according to ground-water considerations:

A. Waste streams which need not be placed into a stable form, but must be segregated from waste streams which have been placed into a stable waste form.

B. Waste streams which should be placed into a stable waste form and disposed in a segregated manner from unstable waste forms. As discussed, a stable waste form could be provided by the disposal facility design (e.g., grouting of the disposal cells), the waste form, waste processing, (e.g., solidification), or the waste package (e.g., use of a structurally stable container).

A third class of waste is also possible based upon ground-water migration considerations. This would include waste which would require additional disposal considerations (e.g., special packaging) or would be generally unacceptable for near-surface disposal.

These tentative waste classes for intrusion and ground-water migration can be combined into a matrix as shown in Figure 7.1 to yield 6 potential separate waste categories. There is no practical use, however, in setting out two

Figure 7.1 Tentative Waste Classification Matrix

	Migration	
Intruder	No Stability Requirements	Stable Waste
Segregated low activity	A	-
Stable, regular disposal	-	B
Stable, intruder protected	-	C

different unstable waste classes: one based on intruder considerations and one based on migration considerations. Similarly, there is no point in setting out classes of waste that must be stable by one consideration but are allowed to be unstable by another. And, if a waste stream is unacceptable by either intrusion or migration considerations, then it it is unacceptable. Therefore, the six potential classes become three and any waste exceeding the upper bound concentration calculated for Class C is generally not acceptable for near-surface disposal.

Such a classification system presents some difficulties in that of the two considerations--intrusion and migration--only the first appears to be directly applicable for waste classification purposes. The calculation of concentration limits for pathways involving exposures to an inadvertent intruder are relatively straightforward since potential exposure of an intruder is directly related to the concentration of the radionuclides available for uptake. It is considerably less straightforward to set out categories of waste based upon migration considerations. Potential ground-water migration impacts could occur to an intruder consuming water from a well located onsite, to individuals consuming water from a well located at the site boundary, or to populations consuming water from a public drinking water supply. Potential migrational impacts are much more a function of site-specific environmental and geohydrological conditions than concentration-limited intruder impacts. Potential migrational impacts are furthermore a function of the total inventory of radionuclides at a disposal site. This means that, unlike concentration-limited intruder impacts, potential migrational impacts are not as directly linked to concentration limit requirements.

The approach that has been taken, then, is to first determine waste classification requirements (based upon concentration limits) considering protection of a potential inadvertent intruder. Then, the nuclides which were determined in Chapter 5 to be important from the standpoint of migration are identified such that inventory limits based upon ground-water migration considerations can be established on a site-specific basis.

7.2 WASTE CLASSIFICATION BASED UPON CONSIDERATION OF A POTENTIAL INADVERTENT INTRUDER

7.2.1 Classes of Waste

Table 7.1 sets out calculated concentration limits for each of the first three classes of waste discussed in Section 7.1. The concentrations are maximum average concentrations for each radionuclide in disposed waste. Column 1 establishes the interface concentration limit between those wastes which must be placed into a stable form and those in an unstable form requiring segregated disposal. Waste containing activity at or below the concentration limit for Column 1 is defined as "Class A" segregated waste. Above the concentration limit the waste is defined as "Class B" stable waste.

Column 2 establishes the minimum concentration for wastes that will require disposal with an additional barrier to inadvertent intrusion. Waste containing activity above the concentrations limit is defined as "Class C" intruder protected waste.

Column 3 establishes the upper bound concentration for waste that is considered to be generally unacceptable for near-surface disposal. Above this concentration limit, the waste is defined as generally unacceptable for near-surface disposal. Such waste will require special consideration and prior approval for disposal near surface. Column 4 has been prepared as an example of disposal of such "unacceptable waste" based upon one potential special disposal technique, the "hot waste" facility, as analyzed in Chapters 4 and 5. Column 4 defines the upper bound concentration of waste that would be acceptable for disposal in such a "hot waste" facility given the assumptions for design and operation set out in Chapter 5.

To establish the limits, the intruder performance objective (500 mrem/yr whole body) is used as established in Chapter 4, an active institutional control period of 100 years is assumed, and the most conservative assumption regarding the waste form is made. For organs other than whole body and bone, a dose limit of 1500 mrem was used. The waste is assumed to be as dispersible as ordinary dirt and no credit is taken for improved waste forms to reduce plant uptake. These concentration limits were calculated using the INVERSE computer code presented in Appendix H.

The table requires some interpretation. To calulate the limiting concentrations in the table, the extensive intruder scenarios used in Chapter 4 (intruder-construction and intruder-agriculture) were assumed for Columns 1, 3, and 4. The delay time prior to initiation of the event was 100 years for Column 1, 500 years for Column 3, and 1000 years for Column 4. In addition, due to the considerable quantity of concrete used in the "hot waste facility, Column 4 incorporates a factor of 10 additional shielding for gamma radiation. For

Table 7.1 Calculated Waste Classification Limits Assuming Worst-Case Waste Form

	(μCi/cc)			
	Column 1	Column 2	Column 3	Column 4
Isotope	Classes A & B*	Class C**	Generally Unacceptable†	††
H-3	36.2	1.1E+8	#	#
C-14	0.750	1.26E+4	0.787	0.836
Fe-55	#	#	#	#
Ni-59	2.15	233	2.16	11.4
Co-60	677	6.68 E+4	#	#
Ni-63	3.45	2.84E+3	70.2	3.03E+3
Nb-94	1.54E-3	0.152	1.57E-3	1.59E-2
Sr-90	3.76E-2	149	735	1.71E+8
Tc-99	0.262	5.55E+4	0.263	0.263
I-129	8.19E-3	14.8	8.19E-3	8.20E-3
Cs-135	84.3	9.85E+3	84.3	84.3
Cs-137	4.47E-2	4.41	460	4.76E+8
U-235	3.94E-2	3.29	3.94E-2	4.39E-2
U-238	4.76E-2	3.97	4.76E-2	4.78E-2
Np-237	4.08E-3	0.340	4.08E-3	4.13E-3
Pu-238	2.76E-2	2.30	0.681	37.6
Pu-239/40	1.04E-2	0.864	1.05E-2	1.06E-2
Pu-241	0.274	1.18E+4	0.501	1.099
Pu-242	1.11E-2	0.923	1.11E-2	1.11E-2
Am-241	7.89E-3	0.658	1.44E-2	3.16E-2
Am-243	6.62E-3	0.552	6.86E-3	7.64E-3
Cm-243	7.946	5.23	8.023	8.099
Cm-244	3.891	52.3	3.929	3.966

*Intruder-construction or intruder-agriculture limit at 100 years
**Intruder-discovery limit at 100 years
†Intruder-construction or intruder-agriculture limit at 500 years
††Intruder-construction or intruder-agriculture limit at 1000 years; Factor of 10 gamma shielding
#Natural specific activity of the isotope.

Column 2, a delay time of 100 years (the end of active institutional control) was used. However, the waste is in a stable form and the potential intruder exposures are considerably less extensive--i.e., limited to those obtained during "discovery" of the waste, the intruder-discovery scenario.

The table reveals that as long as the waste is assumed to resemble dirt, use of intruder barriers and placing the waste into a stable, segregated form often does not result in a real reduction in overall hazard for long-lived isotopes. For long-lived isotopes such as Tc-99, concentrations in Columns 1, 2, and 4 are essentially the same. For other, shorter-lived radionuclides such as Cs-137, Sr-90, or Ni-63, the options of placing the waste into a stable form or disposing of it with a barrier has a large effect upon the concentrations calculated. Also, use of a "hot waste" facility for special high activity waste streams (Column 4) would really not provide any additional long-term protection for long-lived radionuclides but would be very useful for large quantities of shorter-lived radionuclides such as Cs-137 or Sr-90.

For short-lived radionuclides such as Fe-55 (2.5 year half life) or Co-60 (5 year half-life), extremely large quantities of these radionuclides could be disposed of with little or no regard to long-term intruder hazard. The radionuclides decay sufficiently quickly that at time periods much beyond 100 years, intruder hazard is negligible. As shown, there is no limit on the amount of Fe-55 that can be disposed in any class--i.e., the limits calculated for all four columns exceed the natural specific activity of Fe-55. A similar situation is observed for H-3 and Co-60 for Columns 3, and 4. In addition, the limit in Column 2 for H-3 is calculated to be 10^8 Ci/m^3. This is actually somewhat less than the natural specific activity for tritium (2.9 E+9 Ci/m^3) but is obviously sufficiently high that it will not be exceeded on a practical basis.

For Column 2 it is seen that the concentrations for several radionuclides are larger than those presented in Column 3. These are all long-lived isotopes for which disposing of the waste with an intruder barrier does not cause any significant reduction in the potential long-term hazard to an inadvertent intruder. For shorter-lived radionuclides such as C-137 use of a barrier does result in a reduction in potential impacts.

7.2.2 Corrections for Waste Form

As discussed in Chapter 4, the potential impacts from inadvertent intrusion were shown to be reduced through use of improved waste forms. Improved waste forms reduce the potential for waste decomposition, dispersion and uptake by plant roots. Based on the analysis, one alternative that could be applied to establishing concentration limits based on intruder considerations would be to establish separate limits for each waste form. In this way, consideration can be made of the tendency of each waste form to degrade into dispersible, respirable particles, to be taken up by plant roots, or to provide self shielding against direct gamma radiation from the contained radionuclides. In general, however, this would appear to be difficult to do. Some of the reasons are as follows:

- There are in reality innumerable waste forms. It would be extremely difficult to attempt to characterize all possible waste forms and determine concentration limits for each.

- o Regulation would be very difficult. As discussed earlier regarding the alternative of establishing separate concentration limits for each disposal facility, providing separate concentration limits for each waste form would be generally confusing to both regulators and licensees. An occasional exception could be made, however.

- o It is difficult to predict the ability of particular waste forms to minimize dispersion and plant-uptake over the long term. For example, some assumptions have been made in this regard for wastes solidified in material such as cement or synthetic polymers. Although such assumptions may be reasonable, it is difficult to assure that they will be reasonable for thousands of years. For example, it would be difficult to have confidence in the long-term ability of waste forms such as cement to minimize dispersion of long-lived transuranic radionuclides such as Pu-239 over the long term. On the other hand, it is less difficult to have confidence in the long-term ability of waste forms such as activated metals to minimize dispersion of contained shorter-lived activation products.

In general, then, it would be more useful to set out limits applicable to all wastes, and then consider potential allowances for particular waste forms. Two such waste forms for which allowance for waste form should be made are activated or fixed-surface contaminated metals and uranium metal. To briefly summarize from Reference 5 and from Appendix G, many, if not most of the more highly activated metals' waste streams are composed of relatively noncorrosive materials such as stainless steel. Corrosion of such materials takes place at a slow, relatively predictable rate and produces finely-divided but highly insoluble oxides. Crud deposits on such waste streams as LWR nonfuel reactor core components can be very difficult to remove. In addition, the relative amounts of activated metals currently being generated and disposed at radioactive waste disposal facilities are small compared with other waste volumes. Another very small volume waste stream is uranium metals. Uranium metal is occasionally used for gamma shielding in waste transport casks. Other applications include counterweights in airplanes. NRC believes the concentrations of nuclides contained in metals, metal alloys or permanently fixed on metal as contamination can be increased by a factor of 10 to account for the inaccessibility of the nuclides. For natural or depleted uranium the concentrations can be increased to the natural specific activity.

7.2.3 Disposal Facility Design Considerations

This section considers possible variations in waste classes or concentrations in waste classes to account for a particular disposal facility design. That is, depending upon the disposal facility design, different classes or concentrations could be established.

As briefly discussed in Section 7.1 and similar to the argument regarding waste form in Section 7.2.2, if this concept were generally applied to waste classification, then a great multiplicity in waste categories could result. As an example, the effect of different cover thicknesses could be taken into account.

The previous calculations were based on an assumed average 2-meter thickness of earth over the waste, and minor variations on this assumed thickness--e.g., greater than 2 meters--could be incorporated into the calculations. However, this hardly seems worth the effort since as long as one is not speaking of large thicknesses such as 5 meters or intermediate depth disposal, the effect would be small. In any case, the depth of cover at most disposal facilities are often greater than 2 meters, which provides some conservatism into the calculations.

As another example, the calculations in Chapter 5 assumed a disposal efficiency of 0.5 for random disposal and 0.75 for stacked disposal. As discussed in Chapter 5, the higher disposal efficiency would result in higher intruder exposures. This effect could be potentially considered in the waste classification calculations and, depending upon the design of a particular facility, incorporated into classification limits calculated for that facility. However, it is believed to be difficult to actually achieve that high an efficiency level on a practical basis. The effect on intruder exposures would therefore be at most a factor of 1.5 and probably less.

A much more significant effect would be caused by use of grouting to provide additional stabilization of the disposal facility. In the EIS, use of grouting has been estimated to reduce potential intruder exposures by about a factor of 10. This factor is somewhat hypothetical; however, a significantly reduced hazard to a potential intruder would be expected over the short term, although potential long-term reductions in hazard are uncertain.

In general, the NRC staff believes that it would not be useful to incorporate the effect of minor site-specific design variations into the basic waste classification limits calculated. This could result in innumerable waste classes and would be overly confusing to waste generators, disposal facility operators, and regulators. However, it is also recognized that too rigid adherence to this conclusion leads to a loss of needed flexibility to account for disposal designs which would result in the same or improved performance. Therefore, while NRC believes that waste classification can be best implemented and regulated through use of a limited number of waste classes, flexibility should be incorporated into the waste classification requirements to account for variations or improvements in design. This would best be handled through a limited number of assessments carried out on a site-specific basis.

7.2.4 Effect of Environmental Conditions on Intruder Exposures

The previous section discussed the effect of variations in disposal facility design. This section considers the effect of site-specific environmental conditions on the intruder impact calculations themselves. The section is limited to concentration-limited impacts. The effect of site-specific environmental conditions on ground-water impacts is considered in Section 7.3.

On first glance it would appear that significantly higher intruder exposures would be expected at dry western disposal facilities and for the intruder-construction scenario. However, the higher site selection factors are balanced by a number of other compensating factors. One of the principal factors is the significantly lower rate of decomposition of disposed waste that would occur at arid sites. This is borne out by the analysis in Appendix M, which compared measurements of decomposition gas (principally methane) generated as a result of waste decomposition at the humid Maxey Flats, Kentucky facility with the arid Beatty, Nevada facility. The measured methane concentration within disposal trench sumps was several orders of magnitude higher at the Maxey Flats facility. The lower rate of decomposition would result in considerably higher volumes of waste being in a form which is recognizable as something other than dirt. The potential for dispersion of the waste would be considerably reduced, as would the likelihood that the intrusion event occurs in the first place.

Another consideration is the depth of the water table. At many potential western sites, the water table is quite low. At the existing two western disposal facilities at Hanford, Washington and Beatty, Nevada, the water table is on the order of 100 m below the earth's surface. At the southwest regional site, the water table is on the order of 85 meters below the earth's surface. This means that disposal trenches can be (and currently are) excavated to much greater depths than at most humid eastern sites. This reduces the potential for intruder exposures, since layered higher activity waste streams would be placed at comparatively greater depths.

Another consideration is that the intruder-construction scenario occurs for less than a year while the intruder-agriculture event could potentially occur for several years. Higher exposures could potentially be allowed for the construction event, since it occurs over a shorter time period.

In conclusion, it does not appear to be generally useful to include variations in site-specific environmental conditions into the waste classification categories. The range of variation caused by site-specific conditions is expected to be small in the humid eastern sites, where over 75% of the LLW is generated. Assuming that regional disposal facilities are implemented, then this waste would also be disposed at humid eastern sites. Assuming that waste is dispersed by an intruder, then it is possible that higher intruder impacts could result from disposal of waste at arid sites. However, this is balanced by a number of other factors which reduce exposures, one of the principal factors being the greatly lower expected rate of waste decomposition.

7.2.5 Operational Limits--Maximum Average and Allowable Concentrations

The limits in Table 7.1 are maximum average concentrations of individual radionuclides in disposed waste. They were calculated based upon consideration of impacts to a potential inadvertent intruder such that exposure, due to contact with such average concentrations, would not exceed the 500 mrem/yr (whole body) intruder performance objective. If the calculated maximum average concentrations are then set out as the maximum allowable concentrations in waste used as operational limits, they would be applied by waste generators and disposal facility operators in determining the disposal requirements for particular wastes. If they were applied as operational limits, the actual average radionuclide concentrations in the disposed waste in any disposal facility would be less and in most cases significantly less than the calculated maximum average concentrations used in classifying each waste package for disposal. This is due to the mixing (dilution) of all the various waste stream packages containing varying concentrations of radionuclides during disposal (e.g., some waste contains cesium--some at a high concentration and some at a low concentration--and some waste would not contain any cesium). The actual impacts to a potential inadvertent intruder are related to the average concentration of all the waste mixed together during disposal and thus would be less than the intruder performance objective dose limit used to calculate the maximum average concentrations for individual radionuclides.

This is borne out by the results of the analysis in Chapter 4. Using a dose limitation criteria of 500 millirem to the whole body, average volume weighted inadvertent intruder impacts were considerably less than 100 millirem at the end of an assumed 100-year active institutional control period and only a few millirem 400 years later. It was also observed that approximately the same volume-averaged intruder impacts would be achieved if the dose limitation criteria were a factor of 10 higher (e.g., 5 rems whole body). This led to the observation in Chapter 4 that one way to establish an intruder performance objective could be to set out one dose limitation criteria (e.g., 500 mrem) for longer-lived isotopes and a higher dose limitation criteria (e.g., 5 rems) for shorter-lived isotopes. The higher exposures would only last for a relatively short time period. (For example, the potential intruder hazard from Cs-137--half-life of about 30 years--drops by a factor of 10 every 100 years).

The relationship between maximum average concentrations and maximum allowable concentrations (or operational limits) has been addressed by others. For example, NUREG-0456 postulated a maximum-to-average ratio of 10 (Ref. 3). In NUREG/CR-1005, however, the maximum-to-average ratio was not applied (Ref. 3). This relationship was investigated more thoroughly by Healy and Rogers--particularly in regard to dilution by less contaminated waste (Ref. 6). As observed by Healy and Rogers in relationship with trash and other low activity scrap material generated by DOE activities:

> It is the practice in all DOE facilities to consider any material brought into a process or laboratory area as contaminated when it leaves as waste, whether it has contacted radioactive material or not. This is because of the difficulty and expense of measuring each piece of paper, cloth, rubber, etc. to a level that will assure that contamination levels are minimal and acceptable for uncontrolled release. This results in a dilution of the contaminated wastes with this clean material. Some additional dilution arises from the fact that most of the boxes will have lower concentrations than those at the maximum limit set for burial.

The authors then estimate the degree of dilution wrought by this practice. A survey of the five major DOE sites was referenced which indicated that greater than 97% of the waste disposed at these sites is only very lightly radioactive or is suspected of being radioactive because of the place that it is generated. (The 5 sites account for 86% of the total waste volume generated by DOE and 99.9+% of the activity.) As stated by the authors, if it is assumed that the 3% of the waste that is contaminated is at a maximum limit and the remaining 97% is either clean or only slightly radioactive, then dilution by a factor of about 30 would occur. The authors also cite nine months of data regarding the transuranic content of room trash obtained from the Plutonium Research and Development Facility at Los Alamos Scientific Laboratory. From this data, the authors estimate that for a limit of 10 nCi/gm, a dilution factor of 20-60 could be expected for these wastes (Ref. 6).

Finally, Healy and Rogers differentiate between wastes such as trash, where considerable dilution with uncontaminated material would be expected to occur, and wastes such as sludges packaged in degradable containers or ash from incinerated combustibles, which would be expected to be more uniformly contaminated. In their work, the authors incorporated a dilution factor of 20 for material such as trash from water treatment and a dilution factor of 1 (no dilution) for more uniformly contaminated material (Ref. 6).

In the interest of maintaining exposures to levels as low as reasonably achievable, the NRC staff believe maximum allowable concentrations equivalent to the calculated maximum average concentrations should be conservatively set. This minimizes the potential long-term hazard from long-lived radionuclides. NRC staff also believes, however, that there should be flexibility and that exceptions should be considered when there is good reason to do so. Examples would include allowing a higher maximum concentration for short-lived isotopes and/or for concentrations in waste forms that are only present in small quantities.

A specific example in this matter is the isotope Cs-137. This isotope, which is a beta-gamma emitter having a half-life of 30 years, is present in significant quantities in some waste. For example, from 25 to 75 percent of the activity in spent LWR resins can be due to Cs-137. In the analyses performed in Chapters 4, 5, 6, concentrations of Cs-137 were used which were based upon geometric means of a number of data points. However, there was a considerable range in the concentrations in specific data points. It is therefore possible that the analysis in Chapter 4 could underestimate the volume (and costs) of LWR wastes which would have to be processed and disposed by more expensive means. If the Cs-137 concentrations were a factor of 10 higher, the overall intruder hazard at 100 years would not be greatly increased (the volume-weighted hazard would still be less than 500 millirem). Use of the higher concentrations would not effect the long-term potential hazard.

The Cs-137 concentrations may therefore be raised by a factor of 10 in Table 7.1 for Columns 2 and 3. A higher factor-i.e., 20--can be incorporated into Column 1 to account for the preponderance of trash in that class which would contain very low concentrations of cesium or none at all.

7.2.6 Transuranic Isotopes

For a number of years, a de facto limit of 10 nCi/gm has been applied to near-surface disposal of transuranic waste. At one time, transuranic waste was disposed at several near-surface disposal facilities operated by the AEC in addition to 5 of the 6 commercial disposal facilities. However, in 1970, the AEC initiated a policy whereby government-produced wastes containing most TRU isotopes in concentrations greater than 10 nanocuries per gram of waste material were placed into retrievable storage pending transfer to a repository for ultimate disposal. The 10 nanocurie per gram limit was based upon rough comparison with the potential hazards of upper concentration levels of naturally occurring radium in the earth's crust. However, TRU waste generated as a result of AEC (and later DOE) contracts with private contractors and some DOE prime contractors) was still sent to commercial disposal facilities, in addition to TRU wastes from commercial mixed oxide fuel fabrication fabricators and source manufacturers.

Retrievable storage of commercially-generated TRU waste (pending development of an ultimate repository of the waste) by the federal government was the intent of a rule proposed by AEC in 1974. Under this proposed rule, commercial TRU waste would have been consigned to retrievable storage facilities operated by the federal government pending the development of a facility for the ultimate disposition of the waste. A sensitivity level of 10 nanocuries per gram was proposed for measurements to determine the presence or absence of TRU contamination. At the time of the proposed rule, it was expected that commercial recycle of plutonium fuel for use in breeder reactors and in light-water reactors as a mixed oxide would greatly increase in the near future. It was expected that significant additional volumes and quantities of TRU waste material would, therefore, soon be generated.

This rule, however, has never been finalized. The draft environmental impact statement published in support of the proposed rule was withdrawn by the Energy Research and Development Administration (ERDA) when the AEC was reorganized to form ERDA and NRC. The Department of Energy (DOE), ERDA's successor, is continuing the policy of retrievable storage of government-produced TRU waste.

In the meantime, individual state initiatives have resulted in a 10 nanocurie per gram disposal limit for TRU waste at all operating commercial low-level waste disposal facilities. Although at one time five of the six commercial LLW disposal sites accepted TRU waste for disposal (the Barnwell, South Carolina facility has never accepted TRU waste for disposal), this practice has been discontinued. The last commercial facility to accept TRU waste for disposal was the site located in the center of the Hanford Reservation near Richland, Washington and operated by U.S. Ecology, Inc. From 1976 to 1979, the Richland facility was the only commercial disposal facility accepting TRU waste for disposal. TRU waste acceptance at the Richland facility in concentrations exceeding 10 nCi/gm was prohibited by the state of Washington in November 1979.

Prior to the cutoff of TRU disposal at the Richland facility, there was (compared to TRU wastes generated by the federal government) relatively little TRU waste generated by the commercial sector. There is no operating commercial nuclear fuel reprocessing industry, and in 1976, President Carter announced a national policy of deferment of fuel reprocessing. This policy of deferring fuel reprocessing also halted most of the mixed oxide fuel research and development work in the commercial sector. At the time of the cutoff, most of the TRU waste generated from the commercial sector was generated through decontamination of the existing commercial mixed-oxide fuel fabrication test facilities.

Although it has been shown that the federal government and the nuclear industry can readily meet a 10 nCi/gm TRU limitation on near-surface waste disposal--whether as a matter of policy or license condition--there has been interest in deriving a limit by more formal analysis. If a higher limit than 10 nCi/gm could be justified, then there could be an economic gain realized. The earlier classification work (Refs. 2 and 3) suggested that the limit, based upon shallow land burial, could be potentially raised to about 100 nCi/cm^3 (about 60 nCi/gm). However, this limit was calculated based upon use of the older ICRP-2 lung model.

In the work conducted by Healy and Rodgers for DOE to determine limits for shallow land TRU disposal, the newer task group lung model was used, in addition to some different assumptions regarding actions of a potential intruder (Ref. 6). In this work, lower transuranic concentrations were calculated--e.g., in the range of 2 to 50 nCi/gm, depending upon the assumed distribution of contamination in the waste. The lower number was calculated for contamination which is uniform through the waste while the higher number was calculated for contamination which is distributed through the waste so that the average concentration is 5% of the maximum concentration.

Based upon the work performed for this environmental impact statement as well as work performed by others, NRC staff decided not to raise the existing working limit of 10 nCi/gm. This decision is based on several factors. In the work for this environmental impact statement, the newer task group lung model was also used, and as shown in Table 7.1, maximum average concentrations for near-surface disposal of many transuranic isotopes were calculated to be in the range of 10 nCi/cm^3 (the same value for a density equal to water). These calculations are conservative in that they do not allow for dilution by other wastes. In the spirit of the ALARA concept, the lower value of 10 nCi/gm has been demonstrated as an achievable concentration to control the disposal of transuranic nuclides. This value has been imposed by the Department of Energy for some eleven years and by most of the commercial disposal site operators for nearly that long. The last commercial site imposed the 10 nCi/gm restriction in 1979. Thus, there is no need to increase the limit from the standpoint of achievability. There is also a tendency toward a more conservative assessment of the hazard of certain transuranic nuclides (Ref. 13) and it does not seem prudent at this time to use higher calculated values. As more information is obtained regarding the physiological distribution and effects of radioactivity and as improved models describing this distribution are implemented generally more restrictive TRU impacts are calculated. The trend in radiation dose calculations methodology therefore does not appear to generally justify loosening the existing working limit.

In addition, it is believed that most of the potential for economic gain that would result from a higher limit (say in the range of 100 nCi/gm) would be negated by current limitations in routine measurement techniques. That is, it is difficult to routinely nondestructively analyze TRU content in a waste container--particularly in a gamma radiation field. Thus, most waste which currently falls under the heading of being transuranic-contaminated does so because it is suspected of being transuranic-contaminated. For example, it originates from a work area in which TRU isotopes are known to be present. Even if the current working limit were to be raised, it is not likely that the current practice of classifying waste as TRU due to suspicion would significantly change.

In adopting the existing limit of 10 nCi/gm, NRC staff recognizes that the principal concern regarding potential future health hazards of TRU disposal is due to long-lived alpha activity. However, many TRU isotopes are short-lived and/or are not alpha emitters. Some have half-lives less than seconds. Therefore, it is believed to be generally appropriate to restrict the 10 nCi/gm limit to alpha emitters with half lives greater than 5 years. One exception to this rule would be Pu-241, which is a beta emitter which decays with a 13.2 year half-life to Am-241, which is an alpha emitter having a half-life of 458 years. By the time the 100-year institutional control period ends, any Pu-241 disposed in a near surface disposal facility will be approximately one-two hundredths of its former activity. Impacts to a potential inadvertent intruder would mostly result from the daughter product, Am-241. The ratio of the specific activity of Pu-241 to Am-241 is about 35. Thus, to maintain an equivalent limit for alpha emitters of 10 nCi/gm, a limit of 350 nCi/gm could be allowed for Pu-241.

7.3 CONSIDERATION OF GROUND-WATER IMPACTS

The analyses in the previous sections established concentration limits for classes of waste based upon consideration of direct contact of the disposed waste by a potential inadvertent intruder. In this section, additional consideration is given to the impacts of ground-water migration.

Based on the work performed in Chapter 5 and as discussed in Section 7.1, it appears that at least two classes of waste may be established based upon consideration of ground-water migration and long-term costs to a site owner:

1. Wastes which need not be placed into a stable form. That is, the wastes contain sufficiently low quantities of radionuclides that, provided they are disposed in a segregated manner from higher activity waste streams, would not be expected to cause a severe ground-water migration problem.

2. Wastes which should be placed into a stable waste form and disposed in a segregated manner from unstable waste streams.

Clearly, these two waste classes are complementary to the first two classes based upon intruder considerations. In addition, there may also be another class of waste which may contain quantities of radionuclides for which additional requirements for ground-water protection may be needed, or which may not be suitable for near-surface disposal. For the analysis, one approach would be to establish average concentration limits for the above two groundwater classes and to compare the calculated limits with limits developed from intruder considerations. However, this would not appear to be particularly useful. Ground-water impacts are considerably more site-specific than concentration-limited intruder impacts. In addition, groundwater impacts are calculated from the total activity of disposed wastes, rather than the concentrations in any particular waste stream. In addition, ground-water impacts are related to the specific environmental conditions of the site and the design and operation of the disposal facility. Rather than establish concentration limits for radionuclides, a better approach would be to establish inventory limits on a site and facility specific basis for those nuclides that are important with respect to ground-water migration.

In the previous analysis in Chapter 5, the NRC staff has identified three isotopes which are both long lived and mobile. That is, the isotopes move with the approximate speed of the ground water and ion exchange has relatively little effect to retard movement. These isotopes include C-14 (5,730 year half-life), Tc-99 (2.12×10^5 year half-life), and I-129 (1.7×10^7 year half-life). These isotopes have been identified as those contributing the principal long-term ground-water impacts. Tritium has also been identified as an isotope resulting in potentially significant ground-water impacts. Although it is relatively short lived (12.3 year half-life), it has the highest leach factor of the radionuclides considered in the analysis and has a retardation factor equal to 1 (moves with the speed of ground water). In addition, tritium composes the largest inventory of all the radionuclides disposed in the reference disposal facility. As shown in Chapter 5, impacts due to migration of tritium are almost totally observed close to the disposal facility, and it is the most significant contributor to exposures at the boundary well. Farther away from the disposal facility--e.g., at the population well and surface water access location--the ground-water migration time is such that tritium decays to the point that it is not a particular problem.

For these four isotopes, NRC staff believes that each disposal facility should be analyzed on a case-by-case basis and based on the analysis, inventory limits established for each facility that should not be exceeded.

In addition, the analyses in Chapter 5 also identified the fact that the presence of certain chemicals (e.g. chelating agents) in large concentrations in waste increased the potential for migration of radionuclides. Small quantities of these agents contained in waste do not significantly increase the potential for migration. Large single or multiple shipments, however, could affect the long-term ground-water impacts. To address these aspects, wastes containing chelating agents in relatively large amounts (defined by NRC to exceed 0.1% by weight) should be disposed of only upon prior approval of the Commission. This will enable site specific consideration of the increased potential for migration that disposal of these chemicals at the site might present.

7.4 FINAL CLASSIFICATION

This section presents the final classification of waste for near-surface disposal based upon consideration of the previous three sections of this chapter. This classification is presented as a list of radionuclides in Table 7.2. In the table, Column 1 lists the maximum concentrations ($\mu Ci/cm^3$) for "Class A segregated waste." Above these concentrations, the waste must be placed into a stable waste form and disposed in a segregated manner from unstable waste, and so becomes "Class B stable waste." Column 2 presents a list of concentrations above which the Class B stable waste becomes "Class C intruder waste." That is, these wastes must be in a stable waste form, segregated from unstable waste forms, and also disposed with a barrier to an intruder. This barrier

Table 7.2 Waste Classification Table

Isotope	Column 1 Maximum Concentration for Class A Segregated Waste. Above This, It Is Class B Stable Waste μCi/cm³	Column 2 Concentrations Above Which Some Wastes Become Class C Intruder Waste μCi/cm³	Column 3 Maximum Concentration For Any Waste Class μCi/cm³
Any with half-life less than 5 years	700	70,000	Theoretical maximum specific activity
H-3	40	10^8	Theoretical maximum* Specific Activity
C-14	0.8	0.8	0.8*
Ni-59	2.2	2.2	2.2
Co-60	700	70,000	Theoretical maximum specific activity
Ni-63	3.5	70	70
Nb-94	0.002	0.002	0.002
Sr-90	0.04	150	700
Tc-99	0.3	0.3	0.3*
I-129	0.008	0.008	0.008*
Cs-135	84	84	84
Cs-137	1.0	44	4600
Enriched Uranium	0.04	0.04	0.04
Natural or Depleted uranium	0.05	0.05	0.05
Alpha-emitting transuranic isotopes			10 nCi/g
Pu-241			350 nCi/g

*Near-surface disposal facilities will be limited to a specified quantity for the disposal site. This quantity will be determined at the time the license is issued and will be governed largely by the characteristics of the site.

For isotopes contained in metals, metal alloys, or permanently fixed on metal as contamination, the values above may be increased by a factor of ten, except natural or depleted uranium which can be the natural specific activity.

For isotopes not listed above, use the values for Sr-90 for beta-emitting isotopes with little or no gamma radiation; the values for Cs-137 for beta-emitting isotopes with significant gamma radiation; and the values for U-235 for alpha-emitting isotopes other than radium.

Wastes containing chelating agents in concentrations greater than 0.1% are not permitted except as specifically approved by the Commission.

For mixtures of the above isotopes, the sum of ratios of an isotope concentration in waste to the concentration in the above table shall not exceed one for any waste class.

Concentrations may be averaged over the volume of the package. For a 55-gallon drum, multiply the concentration limits by 200,000 to determine allowable total activity.

Until establishment and adoption of other values or criteria, the values in this table (or greater concentrations as may be approved by the Commission in particular cases) shall be used in categorizing waste for near-surface disposal.

could take many forms (e.g., concrete covers), but the minimum acceptable barrier would be disposal so that a minimum of 5 meters of earth or lower activity (Class B) waste, or a combination thereof, separates the waste from the potential inadvertent intruder. Other types of barriers would also be considered on a case-by-case basis.

Column 3 presents a list of radionuclide concentrations above which the waste would generally not be considered suitable for near-surface disposal. Wastes which exceed this concentration would need to be disposed of by disposal methods providing greater protection against potential intrusion. These methods could include much deeper disposal, mined cavity disposal, or special engineered disposal techniques. As noted in Chapter 2, NRC plans to address these other methods in subsequent rulemaking actions.

As discussed in Section 7.1, NRC also considered the use of a specially designed and engineered near-surface disposal facility (a "hot waste" facility) for disposal of wastes containing radionuclides in concentrations exceeding those listed in Column 3. NRC has not listed these concentrations because at this time staff believes that there are some uncertainties involved in use of such a facility and the volume of waste which could require disposal by this method would be small. NRC staff would prefer to address use of this potential disposal method on a case-by-case basis. From the analysis performed, however, the NRC staff believes that such an engineered disposal method would be suitable for wastes containing higher (than Column 3) concentrations of relatively short-lived isotopes such as Cs-137, Sr-90, or Ni-63. The additional long-term protection from longer-lived isotopes would be negligible.

Waste form requirements for the three classes of waste are presented in Table 7.3. These requirements were developed based upon the analyses in Chapters 4 through 6, and can be separated into minimum requirements and stability requirements. The minimum requirements are principally meant to help assure operational safety during handling and disposal, and should be met by all waste classes. The stability requirements are to be met by Classes B and C and are mainly intended to help provide long term structural stability and to minimize potential for inadvertent intrusion into and migration from Class B and Class C waste. In addition, each package of waste must be labeled to identify whether it is Class A, B or C waste and the total activity of H-3, C-14, I-129 and Tc-99 must be shown in the shipping manifest to enable the site operator to maintain an inventory of these isotopes disposed of at each site.

Alpha-emitting transuranic isotopes with a half life greater than 5 years are limited to 10 nCi/gm for near surface disposal. For Pu-241, which is a beta emitter and decays to Am-241, a limit of 350 nCi/gm is established.

As shown on the table, there is no upper limit on the allowable concentration of any isotope with a half-life under 5 years, H-3, or Co-60. The calculated limits exceed the natural specific activity of the isotopes. For isotopes with half-lives less than 5 years in Columns 1 and 2, NRC staff have used the concentration limits for Co-60. This is believed to be conservative, since Co-60 emits two energetic gamma rays. As discussed earlier, there is little cause for concern for potential intruder impacts for isotopes with half-lives less

Table 7.3 Waste Form and Packaging Requirements in Accordance with Waste Classification

Minimum Requirements for all Waste Classes

1. The waste must be packaged and the waste form and packaging must meet all applicable transportation requirements of the Commission set forth in 10 CFR Part 71 and of the Department of Transportation set forth in 49 CFR Parts 171-179, as applicable.

2. Wastes must not be packaged for disposal in cardboard or fiberboard boxes.

3. Waste containing liquids must be packaged in sufficient absorbent material to absorb twice the volume of the liquid.

4. Waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.

5. Waste must not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste.

6. Wastes must not be pyrophoric. Pyrophoric materials contained in wastes shall be treated, prepared, and packaged to be nonflammable.

7. Wastes in a gaseous form must be packaged at a pressure that does not exceed one atmosphere at 20°C. Total activity must not exceed 100 curies per container.

8. Wastes containing biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard.

Stability Requirements for Classes B and C

1. Waste must have structural stability. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a disposal container or structure that provides stability after disposal. A stable waste form will maintain its physical dimensions within 5% and its form, under the expected disposal conditions of compressive load of 50 psi, and factors such as the presence of moisture, and microbial activity, and internal factors such as radiation effects and chemical changes. Stability is intended to assure that the waste does not degrade and promote slumping, collapse, or other failure of the disposal unit and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste.

2. Liquid wastes, or wastes containing liquid, must be converted into a form that contains as little free-standing noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume of the waste.

3. Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.

than 5 years. For example, and as shown in Section 7.2, the calculated limits for Fe-55, which has a 2.6 year half-life, exceeded the natural specific activity of the isotope in all columns. The principal reason for inclusion of classification limits is to help provide some additional operational safety during handling and disposal.

Other considerations are discussed below.

7.4.1 Limits for Ground-Water Migration

The concentration limits in the three columns were established based upon consideration of impacts to a potential inadvertent intruder. The NRC staff also believes that ground-water impacts are of critical importance but recognizes the extremely site-specific nature of ground-water migration and potential impacts. In addition, ground-water impacts are a function of the total inventory of particular radionuclides at the disposal facility, and it is difficult to convert this total inventory to concentration limits. Therefore, NRC has adopted a different approach for ground-water migration.

Based on the analyses in Chapter 5 and as discussed in Section 7.3, four isotopes were identified that are most important with respect to groundwater impacts. For these isotopes--H-3, C-14, Tc-99, and I-129--NRC staff believes that it would be most workable to analyze each disposal facility on a case-by-case basis. Depending upon the specific environmental conditions of the disposal facility, as well as the particular design of the disposal facility, a maximum site inventory of these radionuclides would be derived for the particular site. Then, a running inventory of these isotopes from waste delivered to the disposal facility would be maintained. This will also require special consideration by waste generators for the reporting of these isotopes.

7.4.2 Isotopes Not on List

The table lists 11 isotopes having half-lives over 5 years, natural, depleted and enriched uranium, plus transuranic radionuclides. These are believed to generally cover many, if not most, of the longer-lived radionuclides currently delivered to any disposal facility. Of the hundreds of radioactive isotopes that have been identified, most have half-lives in the range of days or less and only about 100 have half-lives exceeding 5 years. Many of these isotopes are so exceedingly long-lived--e.g., K-40 (1.26×10^9 year half-life), Pt-190 (6.9×10^{11} year half-life), Re-187 (4.3×10^{10} year-half life)--or occur in such small abundances that development of classification limitations is not believed to be of high priority.

However, it is recognized that there are several isotopes--particularly those of heavy metals such as thorium, lead, or radium--for which concentration limits should be developed. Others may also be identified. Development of concentration limits for such radionuclides are planned subsequently. In the meantime, some working concentration limits should be considered for isotopes not presently analyzed. For these, the NRC staff believes a reasonable, yet conservative, rule of thumb would be the following:

- Use of values for Sr-90 for beta-emitting isotopes with little or no gamma radiation;
- Use of values for Cs-137 for beta-emitting isotopes with significant gamma radiation; and
- Use of values for enriched uranium (U-235) for alpha-emitting isotopes other than radium.

For radium, no limits are established as of yet. In addition, the limits established for natural uranium do not consider the ingrowth of daughter nuclides. NRC plans to analyze daughter ingrowth and determine whether the calculated values change based on consideration of daughter nuclides.

Mixtures of Radioisotopes

The list is given for concentrations of single isotopes. However, LLW packages delivered to disposal facilities seldom contain just one radioisotope; generally, the waste packages contain a mixture of radioisotopes. To account for this mixture, NRC staff propose to apply a similar sum-of-the-fractions rule to that described in Table II of the existing 10 CFR Part 20. That is, the sum of ratios of an isotope concentration in waste to the concentrations in the table shall not exceed unity for any waste class. That is,

$$\frac{C_a}{C'_a} + \frac{C_b}{C'_b} + \frac{C_c}{C'_c} \leq 1, \text{ where}$$

C_a, C_b, C_c = concentrations in waste of isotopes a, b, and c;

C'_a, C'_b, C'_c = limiting concentrations in a given waste class for isotopes a, b, and c.

In addition, concentrations may be averaged over the volume of any package. For example, for a 55 gallon drum, the concentration limits may be multiplied by a factor of 200,000 (the approximate volume of a 55 gallon drum in cm^3 to determine the allowable total activity that could be placed in a 55 gallon drum.

7.5 IMPLEMENTATION OF WASTE CLASSIFICATION REQUIREMENT

In order to implement a waste classification requirement, it will be necessary for waste generators to identify and quantify specific radionuclides in the final waste form as shipped for disposal. The concentrations (or total inventories) of the identified radionuclides in each waste package would be recorded on the shipment manifest documents accompanying the waste packages. Also indicated would be the classification of the shipped waste packages (i.e., either Class A, B, or C). The radionuclides listed explicitly in Table 7.2 are of particular importance for identification due to their mobility in the environment and/or their potential hazard to an inadvertent intruder.

This can lead to a number of operational difficulties, since (a) the identity and concentration of radionuclides in each waste package must be determined and entered on the shipment manifest prior to removal of the waste from the generator's facility and (b) the analytical procedures for a number of the radionuclides of interest are complex, expensive, and time-consuming. It is not believed practical in many cases to determine concentrations of all relevant specific radionuclides by direct measurements. In some cases measurements of gross radioactivity may be used; for example, (a) for waste having odd geometries or physical characteristics which make collection of samples and/or data prohibitively difficult; (b) when the total gross radioactivity concentrations are known to be a small fraction of the radioactivity of the mixtures of the radionuclides listed in the relevant column of Table 7.2; or (c) when gross radioactivity measurements are shown to be truly indicative of the actual concentration of the radionuclides contained in the waste. For most higher activity waste streams such as those generated by nuclear fuel cycle generators and occasionally by industrial and institutional generators, however, gross radioactivity measurements may not always be practical or acceptable.

A measurement procedure therefore would need to be implemented in many cases which would be a compromise between the need to identify and quantify specific radionuclides and the practical difficulties in routinely measuring all radionuclides. One solution could be to routinely measure only those radionuclides that can be reasonably and accurately measured without terribly expensive and sophisticated techniques. Concentrations of other radionuclides would be scaled to the measured radionuclides based upon existing or generator-specific data. Additional measurements would be performed to determine concentrations of other radionuclides if the measured radionuclide concentrations exceed given action levels. A more detailed set of measurements could be performed periodically (e.g., annually or semiannually) or after a significant process change to upgrade the scaling factors and the action levels.

For purposes of review and comment, NRC has prepared a specific example on the use of scaling factors and action levels for LWR waste streams. The example reflects the type of guidance which could be set out in a regulatory guide on classification of waste. Two radionuclides which are present in LWR waste streams and can be readily measured by Ge(Li) gamma spectroscopy are Co-60 and Cs-137. In the procedure, these two isotopes would be routinely measured and the concentration of other radionuclides estimated based upon scaling factors developed from either data specific to the facility or from a set of reference scaling factors developed from existing data. Samples may be taken for analysis either from (a) the final waste form, or (b) the waste after any and all volume reduction but prior to solidification. If the concentrations of Co-60 or Cs-137 exceed certain action levels, then other radionuclides would be measured. The action levels used may also be either based upon data specific to the facility or from a set of reference action levels based upon existing data. If the concentrations of Co-60 and Cs-137 do not exceed the action levels, then other radionuclides would not need to be analyzed.

An example set of scaling factors and action levels has been drafted and are included here (Ref. 7). To establish these factors and action levels, estimates of upper-range concentrations of particular radioisotopes were first established.

These upper-range estimates are presented in Table 7.4 and were made based upon maximum reported concentrations obtained from a number of studies performing measurements of transuranic and other radionuclide concentrations in LWR wastes (Refs. 8-11). For a number of radionuclides, however, there was insufficient experimental data. For these radionuclides, upper-range concentrations were estimated based upon use of the scaling procedures used to establish the waste stream concentrations in this environmental impact statement. Concentrations are presented for three BWR waste streams (ion exchange resins, concentrated liquids, and filter sludge) and four PWR waste streams (ion exchange resins, concentrated liquids, filter sludge, and filter cartridges). (Additional information may be obtained from Appendix D, and References 7 and 12.)

Once the upper-range concentrations were obtained, upper-range scaling factors for specific waste streams were calculated. These scaling factors for the above three BWR streams and four PWR streams are given in Table 7.5. Action levels are then calculated by dividing the concentration limits in Table 7.2 by the scaling factors in Table 7.5 to determine the Co-60 and Cs-137 concentrations at which the concentrations of radionuclides more difficult to measure would exceed these respective limits. These action levels for the BWR and PWR waste streams considered are presented in Tables 7.6 and 7.7.

As mentioned earlier, these scaling factors and action levels are believed to be generally conservative and would be used as an option. Generally, a waste generator could develop his own scaling factors and action levels based upon facility-specific data.

Table 7.4 Estimated Upper-Range Maximum Radionuclide Concentrations ($\mu Ci/cm^3$)

	BWRs			PWRs			
	IX Resins	Conc. Liq.	Filt. Sludge	IX Resins	Conc. Liq.	Filt. Sludge	Filt. Cartrg.
H-3	2.27E+02	1.07E+01	2.63E+02	1.44E+02	4.23E+00	1.68E-01	9.52E+00
C-14	6.68E+00	3.15E-01	7.74E+00	1.07E+03	3.12E+01	1.24E+00	7.02E+01
Fe-55	3.69E+02	1.01E+02	9.15E+02	9.75E+01	9.98E+01	6.30E+00	2.83E+01
Co-60	7.34E+01	2.00E+01	1.82E+02	2.54E+01	2.60E+01	1.64E+00	7.14E+01
Ni-59	4.53E+02	1.23E-02	1.12E-01	1.57E-02	1.60E-02	1.10E-03	4.41E+02
Ni-63	4.42E+00	1.20E+00	1.10E+01	1.71E+01	1.76E+01	1.11E+00	4.82E+01
Sr-90	2.17E+00	1.02E-01	2.51E+00	7.10E+01	2.08E+00	8.24E-02	4.68E+00
Nb-94	1.43E+03	3.90E-04	3.44E-03	4.95E-04	5.07E-04	3.20E-05	1.39E-03
Tc-99	2.00E-03	9.45E-05	2.32E-03	4.20E-03	1.23E-04	4.88E-06	2.77E-04
I-129	5.34E-02	2.52E-03	6.19E-02	5.94E-02	1.74E-03	6.89E-05	3.91E-03
Cs-135	2.00E-03	9.45E-05	2.32E-03	4.20E-03	1.23E-04	4.88E-06	2.77E-04
Cs-137	5.34E+01	2.52E+00	6.19E+01	1.12E+02	3.28E+00	1.30E-01	7.39E+00
U-235	1.85E-04	6.10E-11	8.74E-06	5.21E-06	2.39E-07	3.28E-07	7.62E-07
U-238	1.46E-06	4.80E-10	6.88E-05	4.10E-05	1.88E-06	2.58E-06	6.00E-06
Np-237	3.56E-11	1.17E-14	1.68E-09	1.00E-09	4.59E-11	6.30E-11	1.40E-10
Pu-238	7.36E-03	9.85E-02	3.35E-02	1.50E-02	1.03E-02	2.02E-04	2.64E-02
Pu-239/240	4.31E-03	1.44E-02	2.15E-02	2.26E-02	3.60E-02	5.07E-04	3.78E-02
Pu-241	6.29E+01	2.10E+02	3.14E+02	5.47E+02	8.71E+02	1.23E+01	9.15E+02
Pu-242	9.44E-06	3.15E-05	4.71E-05	4.95E-05	7.88E-05	1.11E-06	8.28E-05
Am-241	2.25E-03	1.51E-02	1.72E-03	1.01E-02	3.29E-03	2.64E-04	1.80E-02
Am-243	1.52E-04	1.02E-03	1.16E-04	6.83E-04	2.22E-04	1.78E-05	1.22E-03
Cm-243	2.50E-06	1.50E-05	7.79E-06	9.92E-05	4.43E-06	2.48E-06	2.65E-05
Cm-244	1.77E-02	1.25E-02	4.04E-03	1.76E-02	4.32E-03	1.28E-02	1.51E-02

Table 7.5 Calculated Scaling Factors for LWR Process Wastes

	BWRs			PWRs			
	Resins	Conc. Liq.	Filt. Sludge	IX Resins	Conc. Liq.	Filt. Sludge	Filt. Cartrg.
H-3 to Cs-137	4.25E+0	4.25E+0	4.25E+0	1.29E+0	1.29E+0	1.29E+0	1.29E+0
C-14 to Cs-137	1.25E-1	1.25E-1	1.25E-1	9.55E+0	9.51E+0	9.54E+0	9.51E+0
Fe-55 to Co-60	5.03E+0	5.05E+0	5.03E+0	3.84E+0	3.84E+0	3.84E+0	3.96E-1
Ni-59 to Co-60	6.17E-4	6.15E-4	6.15E-4	6.18E-4	6.15E-4	6.16E-4	6.18E-4
Ni-63 to Co-60	6.02E-2	6.00E-2	6.04E-2	6.73E-1	6.77E-1	6.77E-1	6.75E-1
Sr-90 to Cs-137	4.06E-2	4.05E-2	4.05E-2	6.34E-1	6.34E-1	6.34E-1	6.34E-1
Nb-94 to Co-60	1.95E-5	1.95E-5	1.95E-5	1.95E-5	1.95E-5	1.95E-5	1.95E-5
Tc-99 to Cs-137	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5
I-129 to Cs-137	1.00E-3	1.00E-3	1.00E-3	5.30E-4	5.30E-4	5.30E-4	5.30E-4
Cs-135 to Cs-137	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5	3.75E-5
U-235 to Cs-137	3.46E-6	2.42E-11	1.41E-7	4.65E-8	7.29E-8	2.52E-6	1.03E-7
U-238 to Cs-137	2.73E-8	1.90E-10	1.11E-6	3.66E-7	5.73E-7	1.98E-5	8.13E-7
Pu-241 to Cs-137	1.18E+0	8.33E+1	5.07E+0	4.88E+0	2.66E+2	9.46E+1	1.24E+2
Tru to Cs-137	5.95E-4	5.62E-2	9.84E-4	6.34E-4	1.66E-2	1.06E-1	1.46E-2

TRU Isotopic Scaling Factors

	BWRs			PWRs			
	Resins	Conc. Liq.	Filt. Sludge	IX Resins	Conc. Liq.	Filt. Sludge	Filt. Cartrg.
Np-237 to Cs-137	6.67E-13	4.64E-15	2.71E-11	8.93E-12	1.40E-11	4.85E-10	1.98E-11
Pu-238 to Cs-137	1.38E-4	3.91E-2	5.41E-4	1.34E-4	3.14E-3	1.55E-3	3.58E-3
Pu-239/240 to Cs-137	8.07E-5	5.71E-3	3.47E-4	2.02E-4	1.10E-3	3.90E-3	5.12E-3
Pu-242 to Cs-137	1.77E-7	1.25E-5	7.61E-7	4.42E-7	2.40E-5	8.54E-6	1.12E-5
Am-241 to Cs-137	4.21E-5	5.99E-3	2.78E-5	9.02E-5	1.00E-3	2.03E-3	2.44E-3
Am-243 to Cs-137	2.85E-6	4.05E-4	1.87E-6	6.09E-6	6.77E-5	1.37E-4	1.65E-4
Cm-243 to Cs-137	4.68E-8	5.95E-6	1.26E-7	8.86E-7	1.35E-6	1.91E-5	3.59E-6
Cm-244 to Cs-137	3.31E-4	4.96E-3	6.53E-5	1.57E-4	1.32E-3	9.85E-2	3.33E-3

Table 7.6 Process Waste Action Limits for BWRs

1. Class A Segregated Wastes

Measured Co-60 Conc. (uCi/cm^3)	Waste Stream	Additional Direct Measurements
5.8E+1	Any*	Ni-63

Measured Cs-137 Conc. (uCi/cm^3)		
5.0E-3	CONCLIQ	Pu-242
5.9E-2	FSLUDGE	Pu-241
2.1E-1	CONCLIQ	TRU
2.4E-1	IXRESIN	Pu-241
9.9E-1	Any	Sr-90

2. Class B Stable Waste

Measured Co-60 Conc. (uCi/cm^3)		
1.0E+2	Any	Nb-94
1.2E+3	Any	Ni-63
3.6E+3	Any	Ni-59

Measured Cs-137 Conc. (uCi/cm^3)		
5.0E-3	CONCLIQ	Pu-241
5.9E-2	FSLUDGE	Pu-241
2.1E-1	CONCLIQ	TRU
2.4E-1	IXRESIN	Pu-241
6.4E+0	Any	C-14
8.7E+0	FSLUDGE	TRU
1.4E+1	IXRESIN	TRU

3. Class C Intruder Waste

Measured Co-60 Conc. (uCi/cm^3)		
1.0E+2	Any	Nb-94
1.2E+3	Any	Ni-63
3.6E+3	Any	Ni-59

Measured Cs-137 Conc. (uCi/cm^3)		
5.0E-3	CONCLIQ	Pu-241
5.9E-2	FSLUDGE	Pu-241
2.1E-1	CONCLIQ	TRU
2.4E-1	IXRESIN	pu-241
6.4E+0	Any	C-14
8.7E+0	FSLUDGE	TRU
1.4E+1	IXRESIN	TRU

*Any = IXRESIN, CONCLIQ, FSLUDGE.

Table 7.7 Process Waste Action Limits for PWRs

1.	Class A Segregated Wastes		
	Measured Co-60 Conc. (uCi/cm³)	Waste Stream	Additional Direct Measurements
	5.2E+0	Any[a]	Ni-63
	Measured Cs-137 Con. (uCi/cm³)		
	1.3E-3	CONCLIQ	Pu-241
	1.7E-3	FCARTRG	Pu-241
	3.2E	FSLUDGE	Pu-241
	6.3E-2	Any	Sr-90
	6.5E-2	IXRESIN	Pu-241
	8.1E-2	FSLUDGE	TRU
	8.4E-2	Any	C-14
	4.1E-1	FCARTRG	TRU
	6.0E-1	CONCLIQ	TRU
2.	Class B Stable Waste		
	Measured Co-60 Conc. (uCi/cm³)		
	1.0E+2	Any	Ni-63, Nb-94
	3.6E+3	Any	Ni-59
	Measured Cs-137 Conc. (uCi/cm³)		
	1.3E-3	CONCLIQ	Pu-241
	1.7E-3	FCARTRG	Pu-241
	3.2E-3	FSLUDGE	Pu-241
	6.5E-2	IXRESIN	Pu-241
	8.1E-2	FSLUDGE	TRU
	8.4E-2	Any	C-14
	4.1E-1	FCARTRG	TRU
	6.0E-1	CONCLIQ	TRU
	1.43+J	IXRESIN	TRU
	1.5E+1	Any	I-129
3.	Class C Intruder Waste		
	Measured Co-60 Conc. (uCi/cm³)		
	1.0E+2	Any	Ni-63, Nb-94
	3.6E+3	Any	Ni-59
	Measured Cs-137 Conc. (uCi/cm³)		
	1.3E-3	CONCLIQ	Pu-241
	1.7E-3	FCARTRG	Pu-241
	3.2E-3	FSLUDGE	Pu-241
	6.5E-2	IXRESIN	Pu-241
	8.1E-2	FSLUDGE	TRU
	8.4E-2	Any	C-14
	4.1E-1	FCARTRG	TRU
	6.0E-1	CONCLIQ	TRU
	1.4E+1	IXRESIN	TRU
	1.5E+1	Any	I-129
	1.1E+3	Any	Sr-90
	2.5E+3	FSLUDGE	U-238

*Any = IXRESIN, CONCLIQ, FSLUDGE, FCARTRG

REFERENCES

1. Cohen, J.J., W.C. King, Determination of a Radioactive Waste Classification System, Lawrence Livermore Laboratory, University of California, UCRL-52535, March 1978.

2. Adam, J.A., V.C. Rogers, A Classification System For Radioactive Waste Disposal - What Waste Goes Where?, NUREG-0456, June 1978.

3. Rogers, V.C., A Radioactive Waste Disposal Classification System, Volumes 1 and 2, NUREG/CR-1005, prepared for U.S. Nuclear Regulatory Commission by Ford, Bacon and Davis Utah, Inc., September 1979.

4. U.S. Radiation Policy Council, Progress Report and Preliminary 1981-83 Agenda, RPC-80-001, September 1980.

5. Oztunali, O.I., et al., Data Base for Radioactive Waste Management, Volume 3, Impact Analysis Methodology Report, NUREG/CR-1759, being prepared for U.S. Nuclear Regulatory Commission by Dames and Moore.

6. Healy, J.W., Rodgers, J.C., Limits For the Burial of the Department of Energy Transuranic Wastes, Los Alamos Scientific Laboratory, LA-UR-79-100, January 15, 1979.

7. Wild, R.E., Oztunali, O.I., Regulatory Guide Report, prepared for U.S. Nuclear Regulatory Commission by Dames and Moore, August 1981.

8. Cline, J.E., and D.C. Hetzer, Study of Transuranic Concentration Levels in Solid Radioactive Waste from Commercial Power Reactors, NP-631, Prepared by Science Applications, Inc. for the Electric Power Research Institute, January 1978.

9. Cline, J.E., et al., Activity Levels of Transuranic Nuclides in Low-Level Solid Wastes from U.S. Power Reactors, NP-1052 Prepared by Science Applications, Inc. for the Electric Power Research Institute, April 1979.

10. Cline, J.E., et al., Activity Levels of Transuranic Nuclides in Low-Level Solid Wastes from U.S. Power Reactors, NP-1494, Prepared by Science Applications, Inc. for the Electric Power Research Institute, August 1981.

11. Dames and Moore, Characterization of Selected Low-Level Radioactive Waste Generated by Four Commercial Light-Water Reactors, ORP/TAD-77-3, Prepared for U.S. Environmental Protection Agency, 1977.

12. Wild, R. E., et al., Data Base for Radioactive Waste Management, Volume 2, Waste Source Options Report, NUREG/CR-1759, being prepared for U.S. Nuclear Regulatory Commission by Dames and Moore.

13. International Commission on Radiological Protection, Limits for Intakes of Radionuclides By Workers, ICRP Publication 30, Part 1, A Report of Committee 2 of the ICRP, July 1978.

Chapter 8

REGULATORY PROGRAM--PRESENTATION AND ANALYSIS OF ALTERNATIVES

8.1 INTRODUCTION AND SUMMARY

The regulatory program is the combination of licensing procedures; requirements for recordkeeping, reports, and manifests; and participation by states and Indian tribes. The following discussion presents the existing licensing procedures, requirements for recordkeeping and reports, and state and tribal participation; alternatives and rationale considered; and changes proposed. The licensing procedures are discussed in two parts: (1) the licensing steps and (2) the information requirements and necessary Commission findings. The major changes in the licensing steps are to add a tendering step, to clarify renewals, and to define responsibilities and provide orderly steps after operations cease. The changes in required information and findings are directed at focusing on and complying with the performance objectives, technical criteria, financial requirements, and institutional controls. None of the changes in licensing procedures are judged to be a significant incremental burden. The major changes dealing with records, reports, and manifests are the initiation of a manifest system and specific reporting and recordkeeping requirements on the disposal facility operator. The manifest system requires the waste generator to provide more complete information in the shipping papers and to track shipments. The incremental burden is judged small. The facility operator must submit annual reports keep more complete records and participate in the manifest system. The new requirements reflect, to a large extent, existing practices imposed by host states and are not a significant new burden. The major changes concerning state and tribal participation are to propose a subpart establishing a formal mechanism for state and tribal participation in Commission license reviews, recognition of tribal rights, the initiation of interaction at the tendering step, and documentation concerning landownership and institutional care arrangements. The proposed changes are expected to improve state, tribal, and public participation and have little incremental impact on the applicant, the NRC, or the states, tribes, or public.

8.2 LICENSING PROCEDURES

Licensing procedures are the legal and procedural steps covering and defining the complete life cycle of a licensed activity. Requirements which the Commission must follow and which applicants must follow are included. Existing regulations for receipt of waste radioactive material from other persons for commercial disposal define procedural requirements which the Commission will follow in 10 CFR Part 2. General requirements that are to be followed by all byproduct, source, and special nuclear material applicants and licensees are specified in 10 CFR Parts 30, 40, and 70. Policies and procedures for complying with the requirements of the National Environmental Policy Act (NEPA) of 1969 are prescribed in 10 CFR Part 51. The decisions to be made are which of the existing requirements should be kept or modified, which dropped, and what new requirements should be added. Where the requirements should be located in the regulations must also be decided.

The placement of requirements for procedures for a land disposal facility is a matter of editorial preference and does not affect whether they apply or not and does not affect the impacts. The approach taken was to try and consolidate related requirements as much as possible and to relegate procedures which the Commission must follow in processing applications to 10 CFR Part 2, procedures for applicants and licensees to the new 10 CFR Part 61, and procedures for complying with NEPA to 10 CFR Part 51.

A basic objective in reviewing existing procedural requirements was to limit changes to those which would clearly improve the process. The following discussion will review the existing procedures and then discuss proposed changes including rationale and alternatives considered.

8.2.1 Existing Procedures

8.2.1.1 Licensing Steps

Existing procedures begin with receipt of an application. The application must be docketed upon receipt (10 CFR 2.101(a)). Local site and alternative site governmental officials must be notified by the applicant (10 CFR 2.101(b)), docketing noticed in the Federal Register by the Commission (10 CFR 2.101(d)), and the Governor and state officials notified by the Commission (10 CFR 2.101(d)). An environmental report (ER) must accompany the application (10 CFR 51.40(c)). Provisions such as §30.32(f) of Part 30 require that the ER be filed at least nine months before construction begins; however, 10 CFR 30.33(a)(5) provides that construction cannot begin until NEPA review by the Commission is finished. Under existing rules, hearings are held only if requested by the applicant or interested parties. Hearing procedures are described in 10 CFR Part 2.

After the Commission completes its review and prepares an environmental impact statement (10 CFR 51.5(b)), a decision to issue or deny the application is made. If no hearings have been requested and the decision is to issue a license, the notice of the proposed action must be published in the Federal Register (10 CFR 2.105(a)(2)). If no request for hearings are filed after the proposed action is noticed, the license is issued (10 CFR 2.105(e)) and state and local officials are notified and issuance noticed in the Federal Register (2.105(e) and 2.106(a)(1)). If hearings are requested, they are held in accordance with the rules in 10 CFR Part 2 beginning with hearings before an Atomic Safety and Licensing Board (ASLB). An Atomic Safety and Licensing Appeal Board and/or the Commission may review the findings of the ASLB or the ASLB findings may be appealed to the Appeal Board or the Commission and to the courts. Upon resolution of the hearings, reviews, and appeals a license is issued and noticed in the Federal Register.

After the license is issued it may be amended. Preparation of ERs and EISs is judgmental under Part 51 for amendments. If no hearings are requested and if the amendment involves a significant hazards consideration, it must be noticed in the Federal Register as a proposed action (2.105(a)(3)) and noticed after issuance (2.106(a)(1)). Renewals are handled in the same manner. Continued operation is provided if a timely application for renewal is filed (10 CFR 2.109). Termination of licenses is handled as an amendment and is not specifically mentioned in the regulations.

8.2.1.2 Contents of Applications

Parts 30, 40, and 70 provide general requirements for contents of applications and findings necessary for issuing licenses. The requirements for approving applications are in §§30.33, 40.32, and 70.23(a). A decision that the applicant's training and experience and equipment and facilities are adequate must be made. Procedures must be adequate and the proposed activities authorized by the Atomic Energy Act.

8.2.2 Changes and Alternatives to Existing Procedures

8.2.2.1 Scope of Procedures

A fundamental issue for the procedural aspects of the rulemaking is whether each of the procedures and requirements apply to all land disposal applicants and licensees or just to near-surface disposal applicants and licensees. The licensing steps to be prescribed in the proposed rulemaking should be equally valid for all methods of land disposal. The requirements for contents of applications, Commission findings, and other procedural requirements can also be general for all disposal methods.

8.2.2.2 Licensing Steps

8.2.2.2.1 Tendering

Alternatives to the process beginning with docketing were considered. One alternative was to require a notice of intent 3-6 months before filing an application. The notice of intent would be used to notify governors, legislatures, other state or municipal officials, or tribal governing bodies early in the process. Public concerns could be identified and factored into the applicant's proposal prior to submittal. This alternative was not adopted because: (1) it added an administrative burden on the applicant; (2) from a practical standpoint, it is probably not needed to assure early state input; and (3) its purpose can be accomplished by other means. For example, early state involvement is virtually assured by the "Low-Level Radioactive Waste Policy Act" (Ref. 1) which states that:

> "each State is responsible for providing for the availability of capacity either within or outside the State for the disposal of low-level radioactive wastes generated within its borders except for waste generated as a result of defense activities of the Secretary or Federal research and development activities."

States are reviewing needs, developing compacts, and taking other active measures concerning low-level wastes. Any applicant will have to develop a site in this context. Further, state ownership of the disposal site is likely and evidence of these negotiations are a required part of the application.

The second and preferred alternative was to provide a tendering step. Treating the application first as a tendered document allows the Commission to determine the extent to which the application and environmental report are complete and acceptable for docketing. This should help avoid the delay associated with formally rejecting an application or environmental report that has been docketed and save the costs of reproducing and distributing copies that are incomplete or otherwise unacceptable for processing. Notification of state, local, and tribal officials at this point still allows early knowledge of the applicant's plans. Publication in the Federal Register at this early stage can be used to solicit public views and comments for consideration by the Commission and applicant. If the application and ER are acceptable for docketing as initially submitted, the time between tendering and docketing could be on the order of a month. Depending on the nature of the missing information, the time could be several months or more. Thus at no increased burden or delay for the applicant, a potential method for additional time for public input is provided. A new provision to explicitly state that Commission staff will be available was also added to help assure early interaction with state, county, and municipal officials and tribal governing bodies.

8.2.2.2.2 Docketing

The prescribed activities at the docketing stage for the applicant to distribute copies and the Commission to notice docketing in the Federal Register remain valid. With the tendering steps in place, no alternatives had merit.

8.2.2.2.3 NEPA

The requirements for the applicant to submit an ER and the Commission to prepare an EIS are consistent with NEPA and no alternatives were considered. The existing requirements, however, dealing with when construction may begin could be confusing to applicants. Since construction of a land disposal facility should not be complex or take more than a few months and since existing requirements provide that construction may not begin until the NEPA review is completed, no good reason to change this requirement seemed to exist. The language was, however, simplified. The major benefit of this requirement to not begin construction is to provide flexibility to consider alternative sites without the influence of commitments by the applicant at one site. Site exploration and associated activities are permitted and the commitment to investigate the site cannot be avoided.

8.2.2.2.4 Construction Authorization

The related issue of whether to issue a separate authorization for construction was also considered. Near-surface disposal facilities are current practice and are expected to dominate new applications. This expectation is discussed elsewhere and is the basis for developing specific technical requirements for this type facility first. The building of support facilities such as administrative offices, health physics labs, etc., and preparation of a near-surface facility for beginning operations would not ordinarily involve sufficient commitments to necessitate a separate authorization for construction. The one-step licensing as provided for under existing rules was maintained. If this one-step process should prove a burden for other land disposal methods, such as disposal in a mine, exemptions can be granted for construction work at the applicant's risk. Before authorizing receipt of waste, however, NRC will inspect the facility to determine whether the facility is in conformance with the description, design, and construction described in the application.

8.2.2.2.5 Hearings

The only alternative to holding hearings if requested is to require hearings. This alternative was considered but not adopted for two principal reasons: (1) other means of input into the review of the application and environmental report are available and (2) the desire to minimize the burden on applicants consistent with health, safety, and environmental responsibilities. State, local and county officials, indian tribes, and the public can participate in the EIS scoping process and comment on the draft and final EIS documents. As discussed earlier, the state will probably be involved under the "Low-Level Radioactive Waste Policy Act" and is a potential landowner of the disposal site. Hearings require significant resources of all parties involved and at least a year to complete. If issues can be resolved by less formal methods, all benefit. The proposed revisions to 10 CFR Part 2 include offering a single opportunity for a hearing to the applicant and other affected persons in a Federal Register notice after docketing. The notice would be in accordance with existing requirements in §2.105. Noticing is not required for the applicant or interested parties to request hearings but it serves as a reminder. No changes were considered or proposed for the hearing process as currently defined in Part 2. Opportunity for hearings will also be specifically provided for renewals, site closure, license transfer, and license termination.

8.2.2.2.6 Issuing Licenses

Licenses are issued or denied under §2.103. Only a minor conforming change was considered and it was adopted. Section 2.103 requires, among other things, notification of state and local officials for initial issuance of a license for commercial disposal of wastes from other persons. This requirement was clarified and moved to the Notice of Issuance section (§2.106). The new subsection makes it clear that any action to issue a license for a land disposal facility or amendment of such a license involving a significant hazard consideration will be noticed in the Federal Register and officials notified regardless of whether hearings are held or not. No other changes to the amendment process were considered or proposed.

8.2.2.2.7 Renewals

Experience with existing sites has demonstrated a need to clarify the renewal process as it applies to disposal. Two alternatives were considered. One was to delete the provision for license expiration altogether. The license would remain in effect until terminated. The disadvantage of this alternative is primarily the lack of incentive to update the license to reflect the developing state-of-the-art technology and to fully factor operating experience and new site information and site performance into periodic reassessments of site operations and planning. The advantages are the reduced burden in fees and resources devoted to the renewal application by the licensee and in review by the Commission. The discipline of periodic renewals was chosen as the preferred alternative. Other means of updating the license requirements such as submitting reports or reassessments under specific conditions of the license do not provide the same degree of assurance that the licensee and the Commission will act. Consistent with existing Commission practice for other licensees, no specific period for the renewal is specified in the regulations. For most licensees the usual period specified by specific license conditions is five years. Shorter or longer times are specified as judged appropriate. This same flexibility was retained.

The scope of the renewal process was also clarified based on experience with the existing sites. The renewal applies only to continued waste receipt and disposal operations not the licensee's continuing responsibility for disposed wastes. Existing specific license conditions for the Barnwell, South Carolina and Richland, Washington sites reflect this scope.

8.2.2.2.8 Closure

If the licensee no longer wishes to receive wastes, the licensee must file an application for site closure. Existing rules such as §30.34(f) require that licensees notify the Commission when they plan to discontinue licensed activities. Such procedures may be adequate when sealed sources, very small quantities, or very short half-lived materials are involved. They are not adequate for an orderly preparation of the disposal site for custodial care by the landowner. The closure activities are sufficiently important that specific provisions and guidance for this type of amendment was judged necessary and a less formal approval unacceptable. No alternatives were considered.

8.2.2.2.9 Postclosure

Once closure plans are approved by specific license amendment and implemented, several choices exist. The license can be terminated or transferred or the licensee can continue to control the site for a period of postclosure observation and maintenance. Although much of the work toward closure should be performed throughout the operational period, some final site contouring and preparation may be necessary. These measures need time to stabilize. Additional assurances that the site is performing as expected can be provided by a period of observation and monitoring. If the site closure measures need modification or correction, the facility operator would have the best experience to carry out the modification. Regulatory control and review of these activities provides additional assurances that the public health and safety are protected. The performance objectives to provide stability of the site after closure and to eliminate the need for ongoing active maintenance is aimed at the long-term care period. Continued responsibility of the facility operator for a period of at least five years of postclosure observation and maintenance was judged to provide reasonable assurances without undue burden (see the site closure and stabilization requirements in Chapter 5).

Following the period of licensed postclosure observation and maintenance, the the license may be terminated or transferred to the government agency which is to provide custodial care. The issue of whether the site owner should be licensed and, if so, how, is at the heart of this decision. By permitting use of federal or state land or accepting title to the land, the government agency has accepted responsibility for long-term institutional control of the site. The nature and duration of the controls needed to assure that the performance objectives will be met is one of the findings the Commission must make in licensing the land disposal facility and in all subsequent licensing actions. For most land disposal facilities, reliance is placed on the institutional control and without it the public health and safety cannot be assured. The type of monitoring or surveillance performed might need to be changed during the custodial period based on site performance or other factors. In view of the reliance on institutional controls and the potential need for reassessing the control program, licensing the landowner was judged necessary for the Commission to fulfill its responsibilities.

The final question is how to license the custodial agency. The alternatives considered included: (1) issuing a general license to state and federal agencies for custodial care, (2) termination of the facility operator's license and issuing a new specific license to the custodial agency, (3) transferring an appropriately conditioned license to the custodial agency, (4) making the custodial agency a colicensee when the site is licensed, and (5) requiring that the custodial agency be the only licensee. The general license approach would provide regulatory authority over activities, provide a mechanism for requiring reports and allow inspections. The difficulty is in the site-specific nature of the control program, particularly the monitoring, and in the potential need to alter the program during the institutional control period. The general license does not provide sufficient flexibility and was not selected. Terminating one license and issuing another is procedurally more complex and requires development of specific requirements for contents and reviewing of such applications. Any action to terminate one license would have to be taken concurrently with the issuance of the new license to provide continuity of responsibility. Transfer of the license would accomplish continuity. Both would involve custodial agency consent to be a licensee. Consent by the agency has the advantage that the agency can assure that the site meets any applicable requirements not covered by the Commission's authority and that staff and resources are arranged to implement custodial care. It has the disadvantage that the agency may delay consent beyond the time the operator planned for in his financial arrangements.

Another way to assure continuity is to require that the state or federal agency be a colicensee when the site is initially licensed. The operators's responsibility would be terminated by amending the license to delete the operator and leave the agency as the only licensee. This arrangement does not eliminate the need for agreement between the parties but does provide the greatest assurances of responsibility. Colicensee arrangements involve complex agreements and arrangements between the two parties to clearly define roles and responsibility. Covering all situations can prove difficult. Because of the complexities and uncertainties a colicensee arrangement was not mandated. A final option considered was to require that the custodial agency be the only licensee. Any commericial firm involved would be a contractor only. The Commission has no basis to deny the commercial sector the right to be a licensee under existing authority. This option would require the government agency to be involved in the day-to-day operation at the site. The agency would be responsible for all activities and would, at the very least, have to audit and oversee the activities.

This option would eliminate the potential uncertainties and problems associated with termination, transfer, or even amendment to delete a colicensee.

The option selected is transfer of the license to the site owner. Administrative convenience and continuity are provided at little risk or burden to the licensee. The options for colicensees and site owner as required licensee are not precluded by the preferred option and may well be the option followed in some cases.

Active institutional care will be necessary to protect the public health and safety for a finite period. In analyses and findings throughout the earlier licensing phases, 100 years is the upper limit assumed for institutional control. Unless new information develops or future generations apply different criteria, the license should be terminated when the active institutional controls are no longer necessary and oversight and regulatory authority is no longer necessary. The only alternative is to leave the license open ended. A cutoff point and a specific provision for termination was judged preferable.

8.2.2.2.10 Summary

In summary, the licensing steps have been modified to add a tendering step, to clarify renewal, and to define responsibilities and provide orderly steps after operations cease. Specific license amendments are proposed for site closure, transfer to the site owner, and termination. The changes in licensing steps have been chosen to minimize the burdens on all parties. The incremental impacts caused should be positive in that more specific guidance is provided and roles are more clearly defined. No quantitative estimate of the impacts was attempted.

8.2.2.3 Contents of Applications and Findings

The license procedures also involve information exchange, analyses, and findings at each step. The existing very general requirements do not provide specific guidance to applicants or the Commission. The basic requirements such as complying with the Act, must still be met but questions such as how much detail should be in the regulations and how much deferred to other parts of the regulatory framework (e.g., regulatory guides, branch positions); how much flexibility can applicants and licensees be given and still accomplish the goal of minimizing resolution of issues on a case-by-case basis; and what is the resulting burden on applicants, licensees, or the Commission were considered in analyzing the contents of applications and other actions required. The results hopefully represent a reasonable balance of such considerations.

8.2.2.3.1 Contents of Applications

The principal purpose of the information in an application is to inform the Commission of the nature of the project and the safety evaluations that have been performed to evaluate whether the project can be carried out without undue risk to the health and safety of the public. The documentation of the information is the principal means (a) for an applicant to provide the information needed to understand the basis on which this conclusion has been reached; (b) to be referenced in the license to describe the basis on which the license is issued; and (c) used by Commission inspectors to determine whether the project is being carried out within the licensed conditions.

A listing of the content of an application should be included to serve as a checklist and index to the requirements in the rule. It should be organized topically so that requirements are grouped together according to subject. The topics should include general information, specific technical information, technical analysis, institutional control, financial information, and a catchall: other information.

The general information required includes the identity of the applicant (the information requested should be similar to that requested in existing regulations, e.g., §70.22(a)(1), but should emphasize knowing exactly what corporate arrangements exist); the commitments for financial assurances and the long-term responsibilities of the site operator; a description of the technical qualifications of the applicant (existing regulations, e.g., §70.22(a)(6), already required this information); the organizational structure and maintenance of a trained complement of personnel; and a general description of the planned activity and types of waste to be accepted for disposal (e.g., see existing §§70.22(a)(2) and (4)).

The specific technical information to be included covers the data base needed to demonstrate compliance with the performance objectives and technical requirements. The data base must cover site characteristics, facility design, operating plans, site closure plans, detailed waste description, and procedures for quality assurance, radiation safety, and administrative control.

The technical analyses that should be conducted are those needed to demonstrate compliance with the performance objectives.

Information concerning arrangements for institutional control should be required for two reasons: (1) the importance of the control for assurance of protection of the public health and safety and (2) the desire not to expend Commission and applicant time and resources on projects that cannot be licensed. The state or federal agency that either owns the land where the disposal site will be located or will be expected to accept title to the land before a license is issued will be expected to assume responsibility for institutional control. Under the proposed licensing steps, the state or federal government will also be expected to accept transfer of the license following the postobservational and monitoring period and carry out the institutional control under license. By requiring information in the application that the intended landowner and institutional control agency are aware of and understand their responsibilities and are prepared to accept them, wasted efforts and misunderstandings should be minimized. Two specific provisions are proposed: (1) submission of a certification that the government agency is prepared to accept transfer of the license and (2) submission of evidence that the land is government-owned or that arrangements have been made for assumption of ownership before the Commission issues a license. More flexibility was provided on the ownership issue because ownership must be in place before the license is issued whereas the license transfer occurs decades later. Also, specifying a certification to address all circumstances and to adequately protect the government agency's interests would prove difficult.

Provisions for financial information should require the applicant to demonstrate financial qualifications. Demonstrating financial qualifications is not new. Part 70 notes the option to require this information (§70.22(a)(8)).

A miscellaneous section or other information section was needed to pick up potentially applicable requirements for special nuclear materials (SNM) and provide the Commission the option to request additional information should the proposed activities warrant. Part 73 physical security measures can be referenced to alert the applicant to existing requirements. Any physical security measures would be in addition to provisions for industrial type security and measures to prevent unauthorized access to other materials that would be included in radiation safety and administrative procedures. Part 73 has threshold quantities of SNM expressed in terms of quantities; enrichment and other factors subject to change so referencing was chosen over repetition. Existing practice that such measures should apply only to materials at the facility before disposal was noted. Similar reasoning applies to criticality accident and alarm requirements. Part 73 applicability can be easily provided by amending the purpose and scope Section (§73.1). These changes were needed to maintain the status quo for SNM licensees. Past practices at sites have not warranted physical security or criticality alarms, but the potential for future storage of quantities of concern must be addressed. Requiring criticality control information for materials in storage and emplacement in the disposal unit reflects current practices and was retained.

With respect to the number of copies of the application and environmental report, referencing to eliminate repetition, and updating of application, existing practices should be maintained except that the applicant should file only three copies. The three-copy limit is a provision of the Paperwork Reduction Act of 1980 and even though the Act may not apply since fewer than 10 applicants are expected, compliance with the intent was chosen.

8.2.2.3.2 Findings

All actions taken by the Commission must be consistent with its responsibility to protect the public health and safety and assure that issuance of the license will not be inimical to the common defense and security of the public. In order to structure the considerations the Commission will follow in reaching a decision, specific findings should be listed in the Part 61 rule. Existing regulations (§§30.33 of Part 30, 40.32 of Part 40, and 70.23 of Part 70) also include lists of findings. For example, §70.23 lists findings concerning use consistent with the Atomic Energy Act; technical and financial qualification; adequate equipment, facilities and procedures; materials control; physical protection and security; emergency plans; and principal structures, systems, and components. The proposed findings should be of the same level of detail but structured to focus the findings on the individual performance objectives and track the required content of an application. The findings should also acknowledge that the requirements of Part 51 must be met.

8.2.2.3.3 Conditions of Licenses

The conditions of licenses should reflect existing practices and provisions of Parts 30, 40, and 70. Prescribing specific license conditions in the regulations assures conformity on matters that are important and do not vary from licensee to licensee. Providing the authority to add specific conditions to individual licenses allows the Commission to address the site-specific considerations.

One provision should prohibit transfer of the license without Commission approval. Similar provisions are contained in 30.34(a) of Part 30; 40.41(b) of Part 40; and 70.32(a)(2) and 70.36 of Part 70. Another should provide the Commission the right to require necessary information in writing. Similar provisions are contained in 30.34(e)(4) of Part 30; 40.41(e)(4) of Part 40; and 70.32(b)(5) of Part 70.

A third should provide that the operator's license cannot be terminated until the site has been closed and stabilized and stabilization confirmed. Existing provisions in 30.34(f) of Part 30; 40.41(f) of Part 40; and 70.32(h) of Part 70 require that licensees notify the Commission when the licensee decides to discontinue activities under the license. The activities to be authorized pursuant to a new part for site operators include operation, closure and stabilization of the site, and postclosure observation and monitoring. The operator's responsibility does not cease when receipt of waste stops.

Other provisions should (1) subject the licensee to future rules, regulations, and orders and reflect existing language in 30.34(a) and (d) of Part 30; 40.41(a), (d), and (e) of Part 40; and 70.32(a)(8) and (b) of Part 70; (2) provide that licenses can be modified, revoked, or denied for false statements, compelling new information or failure to comply with the license and Commission rules, regulations, or orders as provided in existing regulations, e.g., 70.61(b) of Part 70 and (3) require that licensees confine activities to those in the license as in 30.34(c) of Part 30 and 40.41(c) of Part 40.

Authority to permit the Commission to add specific and detailed conditions to the licenses in accordance with existing practices as reflected in 30.34(e) of Part 30; 40.41(e) of Part 40; and 70.32(b) of Part 70 should also be provided.

One alternative provision considered was to provide flexibility to licensees to make minor changes to the facility or operating procedures without prior Commission approval. The best approach here was to create a hierarchy of license conditions. One category would be those which would require prior Commission approval and opportunity for hearing. A second category would be those requiring prior Commission approval but no opportunity for a hearing. A third category would be those which could be changed with Commission notification but without prior approval. In accordance with the provisions of Part 2, this would assure that those affecting health and safety would receive prior Commission approval and those involving significant health and safety considerations also the opportunity for a hearing. At the same time, flexibility would be provided to the licensee to make minor changes without waiting for Commission approval.

8.2.2.3.4 License Amendments and Renewals

The provisions for amendments should follow existing practices in §§30.38 and 30.39 of Part 30; 40.44 and 40.45 of Part 40; and 70.34 and 70.35 of Part 70. Existing practices (e.g., §70.33) concerning renewals such as filing 30 days prior to expiration, timely extension, and specifically referencing previously submitted information should be retained. Specification that the Commission will apply the decision criteria and required findings for new applications to amendment and renewal applications should be included. This requirement is based on not compromising the basis for assurances that the performance objectives will be met and is a compact way of stating that the original criteria still apply.

8.2.2.3.5 Application for Closure

The contents of an application for closure should provide the final details of site closure based on all previous analyses and the collective experience during the operating phases. A final closure plan is required to pull all of the information together. Specific references to pertinent site data, test data, and environmental information should be provided as a reminder on the type of information which may have been generated during operation that should be considered in developing the final plan. The Commission findings for issuing an amendment to implement closure are reasonable assurance that the performance objectives will be met.

8.2.2.3.6 Transfer of License

The information needed to determine whether the license may be transferred to the governmental site owner is confirmatory. Evidence that the site has been closed as approved, that the postclosure observation and maintenance has confirmed that the performance objectives should be met, and that the arrangements for transfer are in order must be provided so that the Commission can affirm the readiness for transfer and condition the license for custodial care.

Arrangements for transfer include that necessary transfers of funds and records has been accomplished. This requirement is to provide the custodial agency with the information base needed for future activities such as interpretation of monitoring results or planning of remedial work should it be necessary. Obviously, any funds for long-term care which have not already been turned over to the custodial agency should be transferred for use. The monitoring program should also be in place. For example, the custodian should not have to dig or case monitoring wells, and the custodial agency must be ready to assume the license. This finding is needed to assure that the transfer of responsibility to the site owner is orderly. All technical, institutional, and financial questions must be resolved in a manner acceptable to the site owner so that the custodial role may be assumed under the license.

8.2.2.3.7 Termination of License

The information needed and Commission findings are again confirmatory. The type and duration of custodial care found necessary when licensing the site and the types of wastes to be emplaced must be confirmed. The licensee must also demonstrate that any additional requirements imposed during the custodial period because of new information or requirements have been met.

In summary, as the proceeding discussion has shown, the steps leading to termination (1) acknowledge and address the unique nature of the activity being licensed, (2) focus needed attention on careful planning for closure and transfer for custodial care, (3) provide confirmatory observation, (4) remove existing uncertainties in the process, and (5) make maximum use of experience and operational history. The administrative and procedural aspects of the rule dealing with the licensing steps from tendering through termination do not impose new burdens or cause impacts in themselves. They codify, specify, and focus the process on the long-term performance objectives.

8.2.2.4 Miscellaneous Procedural Requirements

Standard practices concerning tests, inspections, and violations should be adopted.

8.2.2.4.1 Tests at Disposal Facilities

Provisions to require the licensee to permit the Commission to perform needed tests is standard existing practice (e.g., existing requirements in §30.53 of Part 30; §40.63 of Part 40; and §70.56 of Part 70).

8.2.2.4.2 Commission Inspection of Disposal Facilities

Provisions for Commission inspection are also standard existing practice. See, for example, §30.52 of Part 30.

8.2.2.4.3 Violations

Provisions for violations are standard existing practice. See, for example, §30.63 of Part 30.

8.3 RECORDKEEPING, REPORTS, MANIFESTS

8.3.1 Existing Requirements

Waste management involves the licensee who generates the waste, transporters or licensed waste collectors who handle packaged wastes, licensees who treat or repackage wastes, and the licensed disposal facility operator. Each of these licensees must meet a number of existing requirements in Parts 20, 30, 40, and 70 of the Commission regulations concerning transfer of licensed materials, recordkeeping, and reports. For example, §§ 30.41 of Part 30; 40.51 of Part 40; and 70.42 of Part 70 require that licensees verify that the intended recipient's license authorizes receipt of the type, form, and quality of licensed material to be transferred. Further, § 20.401 of Part 20 requires that licensees keep records of disposals made under §§ 20.302 (any method not otherwise specifically authorized in the Commission's regulations which includes disposal facility operators), 20.303 (releases to sanitary sewerage systems) and deleted 20.304 (burial of small quantities in soil) until the Commission authorizes their disposition. Loss or theft of materials must be reported under § 20.402 of Part 20. Sections 30.51 and 40.61 of Parts 30 and 40 require that records of transfers of buried material be maintained for 5 years following transfers. Transfers and receipts of special nuclear material of greater than one gram must be reported on prescribed forms for safeguards accounting under § 70.54.

The collective result of the existing requirements in the Commission's rules is to generate a variety of records for retention by individual licensees. Minimum information requirements are not specified. The special needs for disposal activities including handling, emplacement, and data base generation are not addressed. No manifest or waste tracking system is currently provided.

8.3.2 Need for Manifest

The need for improved accountability for wastes and a better data base is reflected in activities of the EPA and the General Accounting Office (GAO). In rulemakings establishing 40 CFR 262-265 (Ref. 2), the EPA initiated a manifest tracking system for hazardous wastes. The new hazardous manifest system became effective November 19, 1980 and prescribes the requirements for and responsibilities of waste generators, waste transportors, and site operators. Contents of manifests, processing, and tracking shipments are specified. The GAO noted the need for improvements in these two areas for radioactive wastes in its report entitled, "The Problem of Disposing of Nuclear Low-Level Waste: Where Do We Go From Here?" published March 31, 1980 (Ref 3). The GAO recommended that NRC "Determine who the generators of low-level waste are in both the Agreement and non-Agreement States and how much waste each licensee is generating" and "Establish a method to track waste from the point of generation to the point of disposal."

The need for a tracking system for radioactive waste does not stem from a series of known lost or diverted shipments as was the case for hazardous wastes. However, the existing system does not preclude lost shipments. For example, wastes may be transferred by a waste generator to a common carrier for transport to a disposal facility. Under existing rules, the generator would only be aware that the shipment did not reach the disposal facility if he did not receive a bill from the disposal facility operator.

The need to have more specific information on who generated the wastes and waste content has been demonstrated in handling leaking or apparently leaking packages at the commerical burial grounds. Waste shipments are collected by brokers who prepare shipping papers for wastes from multiple generators. The packages and shipping papers did not indicate who actually filled the drums or other packages. If additional information on contents are needed to decide whether to open packages or evaluate the significance of leaking material, the broker could not provide the information.

States regulating the operation of the existing disposal facilities have initiated permitting systems to control who ships waste into the state for disposal. Nevada has a third-party inspection program for evaluating the waste programs of shippers. The states are reacting to the need for better control of shipments and shippers and better data bases.

8.3.3 Manifest

8.3.3.1 General Considerations

To address these needs, the Commission considered a number of alternatives. In developing alternatives, public input, EPA rulemaking, and state experiences were considered. One alternative was to defer to the individual states who host sites and let existing rules and the permitting systems of the state address the issues and not prepare any federal requirements. This alternative was rejected because the Commission recognized the need for positive controls, support of the states' efforts and more specific guidance for its licensees. A federally prescribed manifest system would provide uniformity for Commission licensees and a role for Agreement States to follow to minimize the effect of different schemes developed by different states.

Having decided to propose a manifest system to improve accountability for wastes and the data available, the Commission considered implementing alternatives. The central requirements for a manifest system are contents of manifests and how the manifests will be used. The Commission considered whether to put the manifest requirements in the parts of the regulation under which the waste is or will be generated (i.e., Parts 30, 40, 50, 60, 70, and 72) or in Part 20 which applies to all licensees. Part 20 was selected to centralize the requirement, eliminate repetition in the individual parts, and to avoid the problem of incorporation into new parts as they may be developed.

8.3.3.2 Contents and Format

For contents and format of a manifest, the Commission considered alternatives such as developing a specific form, prescribing minimum content, and how to most effectively use existing requirements for forms and papers. Since the Commission does not have a data processing program in place at this time that would require a specific form, minimum content was chosen. Shippers are already required to prepare shipping papers for radioactive shipments under DOT rules in 49 CFR 172. The DOT rules specifically allow (§172.201(a)(4)) other information to be included in the shipping papers. The least burden on licensees is to allow the use of a single form to meet DOT and NRC requirements. The minimum content identified by the Commission tracks DOT requirements and minimizes the incremental burden. The minimum contents proposed include: (1) the name, address, and telephone number of the persons generating and transporting the wastes; (2) as complete a description of the waste as practicable including type, volume, mass, radionuclide identity and concentration, total activity and chemical form; (3) solidification agents used; (4) 10 CFR Part 61 waste classification information; and (5) a certification of compliance.

The content requirements are somewhat more comprehensive than DOT requirements and reflect the minimal information needed for proper handling and emplacement of the waste at the disposal facility. Identifying the waste generator is new. The need to identify the generator surfaced during 1979 when problem shipments were being investigated. The generator can provide the most complete information concerning the shipment and answer questions concerning matters not covered in the manifest. Under DOT rules the shipper is identified for shipments by water only (49 CFR 172.202(a)(1)). The person transporting the waste would ordinarily provide the shipping papers and would be identified in the letterhead. The EPA hazardous manifest system requires specification of the generator, transportor intended, disposal site, and alternate disposal site. The proposed manifest requirements address generator and shipper in the paperwork and intended receiver through use of the manifest. Identity of the generator is preserved when brokers collect the waste by use of an indexing manifest with generator manifests attached. By attaching the generator's manifest, the broker does not have to copy the data.

The required description of the waste in the proposed mainifest is very similar to DOT requirements and provides for the practicable concept. DOT requires specification of the type or category, amount, names of radionuclides, total activity, and chemical or physical form if not special form. The proposed manifest adds only the requirement to specify the concentrations of individual nuclides as completely as practicable and the total quantity of critical long-lived nuclides which must be total site inventory controlled by the operator under the classification system in Part 61. Knowledge of radionuclide mix is also necessary under DOT rules to determine the type of labeling to use, so even this requirement is only marginally a new requirement. A specific requirement to identify the solidification agents used, if any, was added. Specifying the solidification agent is a subset of describing chemical/physical form that will be readily known by the generator. The current DOT requirements are not specific in this regard so that the agents are not routinely identified. Terms such as solid are used in DOT rules. This data will be of value in identifying generic problems with certain agents and in assessing how to handle leaking or damaged packages.

Specifying the class of wastes based on waste classificaton specifications in Part 61 will be new but not a burden. The determination must be made in order to legally transfer the licensed material. Including the information in the manifest helps the disposal facility operator properly handle the waste by flagging it in the papers which are reviewed before off-loading begins.

The requirement for the waste generator to certify that the wastes are properly classified, described, packaged, labeled, ready for transport, and comply with DOT and NRC regulations is an existing practice. DOT rules (49 CFR 172.204(a) and disposal site host states already require this type of certification. The states also have additional certification and hold harmless provisions which should not be proposed in the revisions to Part 20 since they deal with clarifying state-shipper liabilities and relationships. The areas of certification are very similar to DOT. Only the requirement to classify according to 10 CFR Part 61 and abide by both DOT and NRC regulations is different. As noted above, preparation and classification of the waste according to 10 CFR

Part 61 will be necessary to comply with existing limits on transfers and verifying that the intended receiver is authorized to receive the waste. The Commission now has the regulatory requirement to comply with DOT (10 CFR 71.5 and 44 FR 63083) rules and it inspects and enforces compliance with DOT requirements. Certification is to remind licensees of the requirements and provide additional assurance of compliance.

8.3.3.3 Use

How the manifest is used determines its value in tracking the waste and generating a data base. Many options are possible in prescribing the number of copies, where they are sent, etc. In formulating the requirements for use, the complexity of the generator, broker, processor, and disposal facility operator system dictated that the use be specified by type of licensee. A single requirement would be unwieldy and confusing. The EPA hazardous rules are structured to provide standards, including manifest use, for the generator (40 CFR 262), transportor (40 CFR 263), and facility operator (40 CFR 264 and 265).

8.3.3.3.1 Generator

The Commission has approximately 9,000 licensees but probably only about 1/4 of these licensees ship waste for disposal. Exact numbers are not available since licensees are not required to submit reports on waste generation and transfer. Imposition of a reporting requirement on waste generators was considered but not imposed at this time. EPA hazardous rules require annual reports and provide a form for filing such reports. NRC is not prepared to process such reports, has the advantage of knowing the identity of its licensees, and felt that the manifest data could be processed to provide equivalent information. By the same token, a requirement to send a copy of the individual manifests to the Commission, a contractor, or another federal agency at the time of shipment was considered and dismissed for now. Mailing a copy to the Commission would take only a few minutes to tear off a carbon or xerox a copy. Transfers of SNM are already reportable as mentioned earlier. However, since a computer system to track shipments and to process the data is not in place the requirement was not included.

The manifest tracking system must clearly define responsibilities and be inspectable by the Commission. The system selected provides that the generator prepare the manifest, forward a copy to the intended recipient, include a copy with the shipment, retain a copy as long as needed to track shipments, and investigate late or missing shipments or parts of shipments. The generator is the only choice to complete the manifest. Forwarding a copy to the intended recipient is a new requirement to provide the basis for a crosscheck on shipments. The primary responsibility for assuring that the wastes reach its intended destination is the generator's. If the generator is transferring directly to the facility operator, the generator would forward a copy of the manifest to the operator. If the generator transfers to a broker who collects, stores, and delivers the waste, the broker would acknowledge receipt of transferred wastes and assume responsibility for tracking the waste to the disposal facility. Since the storage time permitted in broker licenses is typically up to 6 months, timely acknowledgement of receipt of wastes by the disposal facility operator to the generator is not practical when a broker is involved. Thus the decision was made to transfer the responsibility. The generator forwarding a copy of the manifest or similar document with the shipment is required to meet DOT shipping paper requirements so no alternatives were considered. No alternative to keeping a copy of the manifest until the wastes reach the disposal facility or are acknowledged by the broker were considered because communications or investigations concerning the waste would be hampered without the documents.

Investigating late or missing shipments or parts of shipments is part of the responsibility for tracking the waste. The alternative of NRC investigating the shipments was considered but dismissed because of the large number of licensees and limited Commission inspection resources and because the generator or broker would be more knowledgeable about the individual shipments and any contractors involved. The numbers of investigations should be small but no specific data are available. Preparing and filing reports on investigations will generate a data base to determine how much of a problem is involved. The licensee would need to document his investigation to show compliance with the regulatory requirement to investigate. A report is a reasonable means to document the efforts. Filing the report with the Commission will allow Commission review of the results to see if Commission followup action is required, and a measure of the number of such incidents. Thus the alternative of just maintaining the reports for inspection was not adopted. Other provisions in the Commission's rules require reports for similar investigations (e.g., 10 CFR 20.402 and 10 CFR 73.71).

8.3.3.3.2 Broker

The waste collector or broker is the licensee who collects packaged wastes from generators, consolidates wastes from many small generators for more economical shipment, and may provide other services to the generator. Brokers number in the tens of licensees. The broker's role has been discussed earlier in two respects: (1) the need to assume responsibility for tracking and conducting any investigations after taking possession and (2) the need for a mechanism to preserve information on the waste generator and how to minimize this burden. The broker is also important to preserving the acceptability of the waste for disposal. The generator must certify proper form, packaging, and classification at the point of transfer but cannot certify the actions of others. A certification by the broker that nothing has been done (such as opening containers and adding wastes) which would invalidate the generator's certification would highlight the broker's responsibility and provide additional assurances. The Commission decided that certification by the broker was preferable to no certification.

8.3.3.3.3 Processor

A licensed waste processor treats or repackages wastes. After receipt of the wastes, the processor becomes the new generator. The original generator cannot control what treatment or changes will occur. Therefore, the original generator's responsibility should end when acknowledgement of the receipt of wastes is received under the proposed system. The information provided by the original generator is a key part of the basis for determining whether the waste classification and characteristics requirements in 10 CFR Part 61 are met and other provisions that must be certified. The processor would probably retain the manifests as records of receipts so a requirement that they be maintained until disposal is accomplished or investigations of late or mining shipments are investigated is not a burden and emphasizes their importance.

8.3.3.3.4 Disposal Facility Operator

The disposal facility operators (currently 2 companies for 3 disposal facilities) are the focal point of the manifest system and data collection. Since the facility is the ultimate destination of waste shipments, the facility operator must notify shippers that wastes were received so that generators or brokers will know whether to begin investigations to trace shipments. Several alternatives for imposing this requirement were considered. A very specific requirement specifying returning a copy of the manifest or some new form to the shipper was considered but not adopted. A general requirement to acknowledge the receipt was considered the least burdensome. Under the general requirement, methods such as telephone acknowledgement, billing, or an annotated copy of the manifest can meet the requirement. This flexibility will permit the operator to use the method best suited for the operator's administrative setup and flexibility from shipment to shipment in case of delays in disposal from the weather, etc.

A new requirement to document the conditions of received shipments and what is done to and with the wastes at the disposal facility would provide a record, focus attention on these activities, and consolidate data in one place. Requirements and practices already exist to perform survey evaluations and repackaging of shipments based on the need to assure safety during handling and emplacement of wastes. Facility operators routinely record the trench or trench location and date of disposal. They are also identifying problem shippers under the state permitting systems. Thus, the requirements to document all of this information on the manifest is not a burden. Certifying that handling and disposal of the wastes was conducted in accordance with the license and applicable Commission regulations provides further assurances that conscious attention was paid to the conditions and regulations.

Maintaining copies of the shipping papers is already practiced at the sites. A requirement to maintain the manifest that is used as shipping paper only codifies exisiting practices. The copies can be carbon, mechanically reproduced, or microfilm. The Commission considered having copies forwarded to the Commission, a contractor, or other agency, but did not require forwarding at this time. No data processing system is in place to handle the data. Maintaining records at the sites assures that the data exists. The Commission, other state or federal agencies, or the facility operators can access the data and conduct surveys or studies as needed. The current concern is that it exists. One site operator already has a computer data processing system in place to record information about the shipments. Imposing data processing on the site operator was considered but not adopted for two reasons: (1) to allow flexibility and (2) the federal agencies have been exploring a common data base and the feasibility of one national data processing capability.

Maintaining manifests is not a significant space burden. An estimate of the physical size of the records can be made from reviewing data provided for 1979 for the Barnwell site under contract to NRC. Copies of all shipping records were provided in 38 volumes. Each record is 8-1/2" x 14". The 38 volumes are collectively about 63" thick. The total volume of the records is therefore 7,500 cubic inches which is equivalent to 4.3 cubic feet. The records are from the disposal of 2.2×10^6 cubic feet of wastes. Nationally, 2.9×10^6 cubic feet of waste were disposed of so that nationwide the shipping records for 1979 would be about 5.7 cubic feet. No single facility will probably routinely handle volumes larger than Barnwell's 1979 volumes. Most will handle half or less.

8.3.3.3.5 Crosschecking

Under the proposed system the prime responsibility for tracking shipments is the shipper's. However, since no NRC or federal computer system is in place to crosscheck whether shipments reach their destination, other means of crosschecking was considered. Individual states do not have computer tracking systems in place although such systems for tracking hazardous waste are being developed. As these systems are developed, joint use could be explored for crosschecking and enforcement. A national manifest is also being developed for hazardous waste that would standardize data for computer input. A major difference between tracking hazardous and radioactive wastes is that hazardous wastes typically do not cross state lines (or cross fewer lines) than radioactive wastes typically do. A voluntary cooperative program with the states to track shipment might work but it would be difficult to coordinate and implement. If and when regional compacts are in place as provided by the December 1980 "Low-Level Radioactive Waste Policy Act," such tracking may be included or equivalent accounting provided under the terms of the compact arrangement. The best interim measure would appear to be for the facility operators to provide a crosscheck. To accomplish the crosscheck, shippers would have to notify the facility operator that shipments are on the way. The simplest way to provide complete data to facility operators on shipments is to forward a copy of the manifest as the shipment is initiated. Mailing copies would only take the time to address an envelope. The facility operator would then periodically check to see that shipments for which advance manifests were received were actually received. Any descrepancies should be reported. Notifying the shipper would provide for resolution or an investigation if necessary. Notifying the Commission would provide a check to see that reports have been filed and allow followup if needed. Because the number of radioactive disposal facilities is small (currently three are receiving wastes), the number of no show shipments due to shipment to alternative facilities should be small and would be a easy matter to resolve. Arrangements are usually made with facility operators before shipments are made to the existing sites. For the Barnwell site, the volume allocation system already results in the operator checking on late or missing shipments. Clerical or administrative time will be required to check for matching paperwork and to notify shippers and NRC.

8.3.3.3.6 Timing

Time limits on certain aspects of the manifest system can assure timeliness and remove uncertainties for the parties concerned. The most critical timing is that relating to beginning investigations of late or missing shipments. The times involved are the transit time, the acknowledgment of the receipt of the waste, and beginning the investigation. The latter two are subject to Commission control. For acknowledging receipt, a range of one day to two weeks was considered. One week was selected to be both timely and to allow the disposal facility operator to have a regular schedule and possibly combine billing and notification. Since cross-country shipments may be involved and weather can be a factor, shipment to the disposal facility can take a week. Similiar consideration could apply to receipt by waste collectors and processors. Allowing 3-4 days for the acknowledgment to reach the shipper in the mail adds up to 17-18 days from the time of shipment to the receipt of acknowledgement. Thus, a time limit of 20 days appears both reasonable and timely for the initiation of an investigation. Longer times were considered but the longer the delay, the more chance for loss of control or not correcting a mishap.

Since the disposal facility operator check and audit of advanced versus received manifests is a backup system, the timing should not be as critical. Allowing about a month for the shipper to investigate and late shipments to arrive is arbitrary but reasonable. Therefore a 60-day limit was set for reporting. No specific time limit was set for investigating shipments because of the variety of situations which could occur. A few hours or days should be typical. Once the investigation is complete a timely report will enable timely Commission review of the report and Commission action if required. The licensee does need time to prepare the report and process it administratively. An upper limit of 2 weeks was selected.

8.3.4 Transfers

Changes to 10 CFR Part 20 should also include additional provisions governing transfers. The requirements should be placed in Part 20 for the same reasons the manifest system was. Two new requirements should be proposed for licensees generating wastes or treating and repackaging wastes. One should require that licensees prepare wastes so that the waste is classified according to Part 61 requirements and meets the waste characteristics requirements. No alternatives were considered other than where to put the requirement on waste preparation in the rules. Placing the requirement directly on the generating licensee provides a more direct and enforceable method of assuring waste form and content than relying on existing requirements for transfers. The second requirement is a requirement for a quality assurance program to assure that waste form and content comply with classification and characterization requirements. Good practice already dictates that licenses have quality assurance programs for activities under license. To illustrate, in Inspection and Enforcement Bulletin No. 79-19, issued August 10, 1979 (Ref. 4), concerning packaging of low-level radioactive waste for transport and burial, the importance of assuring compliance with regulations and disposal facility licenses and requirements was emphasized. Controls, audits, and training were noted as necessary to assure safe transfer, packaging, and transport. Complying with the new waste requirements in Part 61 is the generator's responsibility and the new provision would only codify it.

8.3.5 Part 61 Recordkeeping and Reporting Requirements

The recordkeeping and reporting requirements to be included in 10 CFR Part 61 apply to operators of land disposal facilities only. As indicated earlier, such operators subject to Commission authority are expected to number less than ten.

8.3.5.1 Recordkeeping

To adequately define recordkeeping requirements, the types of records to be maintained, the methods and periods of maintenance, and transfers of records should be addressed. The requirements to be included in Part 61 should generally reflect standard practices for Commission licensees except that summary records are to be transferred to local and state officials. Transferring summary records to the local, county, and state officials at license termination increases the institutional knowledge and enables better planning by these groups should questions or problems arise concerning the site after active institutional control ceases. Other recordkeeping matters for disposal facility operators were discussed under manifests. Case-by-case consideration of additional recordkeeping requirements can be made through license conditions.

8.3.5.2 Reports

The same case-by-case flexibility should be provided in the reporting requirements. The proposed reporting requirements should generally reflect current practice for other Commission licensees except for the submittal of annual financial reports. Monitoring the financial reliability of the licensee gives added assurances to financial surety arrangements. The burden of this new requirement was minimized by asking for copies of financial reports prepared in the ordinary course of business, if any. No separate reports would have to be prepared.

Certain reporting requirements are necessary because disposal facility licenses will be issued under Part 61, not Parts 30, 40, and 70 as in the past. For example, safeguards reporting requirements are contained in §§30.55, 40.64, 70.53, and 70.54 of these parts. When the quantities of materials would be subject to the requirements if licensed under Parts 30, 40, and 70, no good reason exists to exempt materials in storage at the facility. Existing practice not to require inventory reports for materials after disposal should be codified for clarity. Rather than repeat the applicable section, they should be referenced. Referencing conserves space and eliminates the need to change Part 61 should the requirements change. The referencing approach was taken for reporting loss or theft of special nuclear material and criticality and controlling transfers of materials by facility operators. (Most licensed material received and possessed at the facility will be disposed of at the facility but occasional shipments to other disposal facilities or licensees may occur.)

An annual report concerning effluent releases, environmental monitoring, maintenance, disposed waste, and variations in site characteristics should also be included. Existing requirements for reporting effluent releases in §40.65 of Part 40 and 70.59 of Part 70 are similar for uranium mill tailings, processing and fuel fabrication, scrap recovery and uranium conversion licensees. No reporting requirements for land disposal licensees could have been proposed or the reporting could have been limited to effluent releases but other areas of concern are of equal or greater concern in waste disposal. Little or no effluents are expected from land disposal facilities but this expectation should be confirmed. Existing facilities in New York and Kentucky experience releases from trench water treatment but such releases are the exception, not the rule. Maintenance activities help measure site performance and identify problems to consider in site-closure planning. Trends in environmental monitoring can be early indicators of problems even if action levels prescribed in the license are not exceeded. Summary reports of disposed waste are already provided to state officials so that reporting this information reflects current practice. Describing any instances in which observed site characteristics are different from those described in data forming the base for issuing a license is important for determining whether the initial findings are still valid. New information about the site will be available each time a trench is excavated which will confirm initial findings or differ. Since the reports are more comprehensive, annual reports are proposed instead of reports every 6 months to minimize the burden.

8.4. STATE, TRIBAL, AND PUBLIC PARTICIPATION

The purpose of this section is to review existing provisions for state, tribal, and public participation in the licensing process, discuss alternatives considered, and review proposed changes to the existing provisions.

8.4.1 Existing Provisions

State, tribal, and public participation was generally discussed in the preceeding general analysis of the licensing process. Steps in both the licensing process and the process for environmental impact assessment and review under the National Environmental Policy Act (NEPA) contain requirements of both the applicant and the Commission to ensure public and state participation.

8.4.1.1 Docketing

10 CFR Part 2 requires that the applicant provide a copy of the application and environmental report to the appropriate municipal or county officials of the proposed site and notify officials of alternative sites identified. Copies of the application and report are to be provided by the applicant to the alternate site officials upon request. The Commission is required to notice docketing in the Federal Register and notify the Governor or other appropriate state officals of docketing.

8.4.1.2 Hearings

Hearings are not required by existing rules. The rules do provide that the applicant or interested parties can file a written petition for a hearing and for leave to intervene. Affected states, tribes, and members of the public could qualify as interested parties. The Commission either accepts or rejects the request for hearings. If hearings will be held, the Commission must notify the Governor of the host state or other appropriate official and the officials of the municipality as appropriate. The hearing process also provides for limited appearances by persons who are not the applicant or intervenor. Limited appearances involve presentation of oral or written statements on the issues at any session of the hearing or any prehearing conference. The regulations also provide that state, county, or municipal agencies may participate, introduce evidence, interrogate witnesses, and advise the Commission without taking a position on the issues. Findings, exceptions, and briefs may also be filed at the hearing board's discretion. Hearings may be requested for initial applications and subsequent license amendments including license renewals.

8.4.1.3 Docket Files

The Commission maintains docket files on all docketed cases. When hearings are involved, the docket files include all pertinent records such as transcripts, orders, and notices. The docket files may be reviewed in the Commission's Public Document Room at H Street.

8.4.1.4 Landownership

Existing rules in 10 CFR Part 20 require that "the Commisson will not approve any applications for a license to receive licensed material from other persons for disposal on land not owned by the federal government or by a state government." States have traditionally accepted the role as landowner and entity responsible for long-term care of the disposal facilities. Assumption of this responsibility has afforded the states an opportunity to participate in site selection and to be involved in the applicant's developmental plans.

8.4.1.5 Low-Level Radioactive Waste Policy Act

This law, enacted in December 1980, establishes the individual state's responsibility for providing for disposal capacity for waste generated within its borders except for defense and federal research and development wastes. It provides for formation of regional state compacts to meet this responsibility. State planning and formation of compacts will afford a means for state involvement in development of new sites and in defining use of existing sites.

8.4.1.6 NEPA

Licensing commercial radioactive waste disposal by land burial is specifically listed in 10 CFR Part 51 as an action requiring preparation of an environmental impact statement (EIS). Whether to prepare an EIS for amendments and renewals is judgmental. If prepared, the same procedures followed for initial licensing would be followed for amendments and renewals. The Commission is required in Part 51 to notice its intent to prepare an EIS. Input from any source can be solicited by the Commission for the EIS scoping process. The applicant's environmental report is widely distributed for reaction and comment. Once drafted, the EIS must be distributed to federal, state, and local agencies and interested members of the public for comment. The availability of the draft must be noticed and press releases issued addressing the desire for comments and availability of the document. Comments and input from all these sources are used to prepare the final EIS. If hearings are held, the final EIS is normally submitted as a major portion of the staff's testimony. The EIS process also gives due consideration to compliance with other environmental quality standards and requirements imposed by federal, state, and local agencies. The final EIS must be noticed and distributed in the same manner as the draft. To the extent practical, the final EIS must also be distributed to all parties who commented on the draft. All sustantive comments must be included and addressed in the final EIS. Responsible opposing views not adequately addressed in the draft must be discussed in the final EIS.

Copies of the environmental report, draft and final EISs, comments, and documented findings are placed in the docket files for public inspection.

8.4.2 Changes and Alternatives to Existing Procedures

8.4.2.1 General

In deciding whether to modify or supplement existing procedures for state, tribal, and public participation, the Commission considered factors such as the desire to foster early involvement so that issues are identified early in the process so that decisions may be made with less delay, the desire to reach all affected parties, and recognition that the applicant, Commission, and public should not be unduly burdened. Another important consideration is the policy set out in the Indian Self-Determination and Education Assistance Act (25 USC 450) (Ref. 5) to foster Indian participation in matters affecting them and self-determination by Indian people.

Although Indian tribal governments can participate as interested parties in hearings and comment on draft and final EISs under existing procedures, no special recognition is provided and the tribal governments are not listed in lists of appropriate officials. In proposed revisions to Part 2 and proposed provisions in the new Part 61, tribal governments should be explicitly included to provide additional assurances that they are informed and included in the licensing process and that early input is solicited. The specific recognition of tribal rights and concerns is important in and of itself also.

8.4.2.2 Docketing

The decision not to add a notice of intent to the front end of the licensing process was discussed earlier as was the addition of the tendering step prior to docketing. The proposed tendering step includes making Commission staff available for consultation and soliciting views and comments from states, tribes, and the public in the Federal Register and local newspapers. The existing requirements on the applicant and Commission upon docketing were retained. The Commission also considered more explicit requirements such as requirements for mandatory public meetings, noticing these public meetings in the newspapers, mandatory location for meetings, mandatory local public document rooms, and toll-free informational telephone numbers. While these ideas for methods of fostering and facilitating public, state, and tribal participation have merits, the Commission chose to consider such methods on a case-by-case basis rather than impose them in the regulations. Because the state will probably be involved in the development of the site, many of the measures may not be warranted. Not requiring the measures does not preclude the implementation of one or all.

8.4.2.3 Hearings

The states, tribes, and public have ample opportunity to participate in the hearing process under existing requirements. As discussed earlier, mandatory hearings are not justified. No changes are proposed.

8.4.2.4 Docket Files

Changes to existing requirements considered were mandatory local public document rooms, mandatory public docket files in regional NRC offices, and more specificity about headquarters public document rooms. The Commission currently arranges local public document rooms or similar arrangements for active licenses for commercial disposal of wastes and expects to continue this practice. Case-by-case flexibility for local document rooms is preferable in case the state has made other arrangements or lack of interest or willingness for a local group to accept responsibility for maintaining the files. Similar considerations apply to regional files. Requiring rule changes for administrative handling of headquarters files is the major reason no additional specificity was proposed for these files.

8.4.2.5 Landownership

The need for institutional control dictates the continuation of the governmental ownership requirements. The Commission considered whether tribal ownership should be included. While the tribal governing bodies could, in many cases, provide the long-term institutional stability at the heart of this requirement, the responsibility and burden far outweigh any economic benefits to the tribe from the operation of the facilities. Furthermore, the state and federal government have responsibility for protecting and considering the interest of the state or nation as a whole. Tribal ownership was not proposed.

As discussed earlier, the applicant must demonstrate that arrangements for institutional control are in order. By requiring certification that the custodial agency understands and is prepared to accept the responsibility and license for institutional control, early negotiations with the agency are assured. Similar assurances stem from demonstrating landowner arrangements. Since the state will probably be the landowner, early state involvement is almost guaranteed. One alternative considered was to require state or federal ownership of the land at the time the application is filed. The Commision certainly wants to allow consideration of state and federal land in the site selection process. Requiring early transfer of land not state or federally owned could influence consideration of alternative sites. The applicant would have a significant financial commitment in acquiring the land compared to the commitment involved in an option. The government agency would also have to accept responsibility for the site before Commission review was completed and delays could result from determining that the proposed activities meet all requirements of the agency. Thus, this alternative was not adopted.

A general certification requirement would allow flexibility yet assure that applicant and Commission resources are not expended when the government agency knows it is unwilling to commit itself to a site. The Commission has no authority to force a state or federal agency to assume the responsibility for site ownership and institutional care. It can only refuse to issue a license if these responsibilities are not accepted. The commitment made by the government agency can be conditioned as desired with respect to issues and matters not preempted by the Atomic Energy Act. Even a provisional commitment should involve some process to involve the public. Several of the regional workshops on the draft rule suggested that a potential host state conduct a process like that for a finding of "public convenience and necessity" for proposed power plants. The Commission cannot require such a process but expects that whatever method will be used will involve opportunity for public comment and consultation with affected jurisdictions. According to state participants in the western regional workshop, intergovernmental consultation may be especially important when disposal is proposed on federal land and hopefully the federal land manager would include such consultation before making a commitment. The government agency commitment does not limit participation in the licensing proceedings under Part 2 or Part 51.

The Commission also considered requiring a certification from the intended landowner. Trying to word the certification to include all conditions and qualifications and cover all situations proved difficult. Another alternative considered and rejected was to require a commitment concerning all alternative sites identified in the application or environmental report. The proposed requirement should apply only to the proposed site. If an alternative site is found preferable, a commitment from the alternative site landowner can be obtained at that point in the proceeding. This arrangement is judged to be the least burdensome to all parties.

8.4.2.6 NEPA

The Commission has a separate rulemaking to update Part 51. No changes to NEPA activities were considered.

8.4.2.7 Participation by State or Tribal Governments

New requirements for participation by state or tribal governments should be established and patterned after the new Subpart C of 10 CFR Part 60 for high-level wastes. The subpart provides a formal mechanism for approving participation in the license review process. It does not grant any new rights or authorities but highlights an existing opportunity and outlines how the states can take advantage of the existing opportunity. Based on input from the states, such highlighting and structuring is needed.

The logical points to address in setting up a formal process are who should initiate the action; where, when, and how to submit an initiating proposal; what to include in a proposal; and how the proposal will be approved.

A request for formal participation should be prepared by the state or tribal governing body and submitted to the director no later than 120 days after docketing of the application. The 120 days is the same time frame as provided in 10 CFR Part 60. It provides a reasonable time to consider filing and preparing a proposal but precipitates action while Commission review is still in its early stages.

The content of any proposals must adequately define what the state or tribe proposes to do. The proposed topics include identifying issues, impacts, products, and plans for local government and citizen participation. The suggested elements do not preclude submission of any other information the state or tribe desires.

The approval process should include meetings to discuss the proposal, decision criteria, and an appeal provision. No other changes to the basic approach set out in Part 60 were considered or adopted.

REFERENCES

1. Nuclear Waste Policy Act of 1980, P.L. 96-573.

2. U.S. Environmental Protection Agency, 40 CFR Parts 260-265 Hazardous Waste Management System Regulations, Federal Register 45 FR 33066-33588, May 19, 1980.

3. U.S. General Accounting Office, The Problem of Disposing of Nuclear Low-Level Waste: Where Do We Go From Here? EMD-80-68, March 31, 1980.

4. U.S. Nuclear Regulatory Commission, Office of Inspection and Enformcement Bulletin No. 79-19, Packaging of Low-Level Radioactive Waste For Transport and Burial, August 10, 1979.

5. Indian Self-Determination and Education Assistance Act, P.L. 93-638, January 4, 1975.

Chapter 9

FINANCIAL ASSURANCES FOR CLOSURE, POSTCLOSURE, AND INSTITUTIONAL CONTROL

9.1 INTRODUCTION

This chapter reviews the need to require financial assurances of licensees for closure, postclosure care, and active institutional control of a low-level waste disposal facility and presents the technical requirements developed by the staff to address this need. In Section 2, the staff presents their rationale of why it is necessary to require financial responsibility of low-level waste disposal licensees for closure, postclosure, and for active institutional control. Section 2 also summarizes operating experiences at low-level waste sites, and reviews federal and state regulatory precedents in this area. Section 3 presents the staff's development of technical requirements to assure adequate funds are available for final closure and postclosure care at the site. The section presents the staff's review of financial assurance mechanisms, and discusses the criteria for evaluating these alternatives. Section 4 presents the staff's development of technical requirements for financial assurances to cover costs during the long-term (institutional control) period.

Table 9.1 presents an overview of the financial assurances required at the various stages of the life cycle of a disposal facility following the proposed requirements in 10 CFR Part 61.

For a more detailed analysis of the financial assurance requirements for closure and for long-term care, as well as a history of the operating experiences at the low-level waste sites, and a review of federal and state precedents in the area of financial responsibility for hazardous waste sites, the reader is referred to Appendix K of this Environmental Impact Statement.

9.2 NEED FOR FINANCIAL PROTECTION REGULATIONS

Financial assurance requirements for low-level waste disposal facilities are needed to help ensure the long-term protection of the public health and safety and the environment. A review by the staff of the operating experiences at both hazardous waste and LLW disposal sites reveals that operators of both types of sites did not adequately plan for closure and long-term care activities. With respect to the LLW sites, the state and federal governments recognized the need to care for the sites over the long term. The sites had to be located on federal or state government-owned land and funds were collected for long-term care activities. In most cases, however, the funds collected for long-term care activities (e.g., the Maxey Flats, Kentucky site) were not adequate and there was essentially no financial planning for contingencies that might occur, (e.g., the need to pump trenches and treat trench leachate). In addition, until recently little planning or financial assurance was provided for funding the final closure and stabilization of the existing sites. This has led to a situation where financial responsibility for the continued assurance of protection of the public health and safety at several of the existing closed sites already has or could become a responsibility of the state or federal government. Early proper financial planning to assure the availability of

Table 9.1 Life Cycle Financial Assurances for a Disposal Facility Following Proposed 10 CFR Part 61

Time in Years	Activity	Form of Financial Assurance
1-2 yrs	Site Selection and Characterization	Licensee responsible for costs incurred
1-2 yrs	Licensing Activities	Licensee responsible for costs incurred including licensee fee
		Site closure plan including cost estimates for closure is submitted as part of licensee application
		Lease arrangement with long-term care arrangements for financial responsibility between licensee and state submitted for review to NRC for adequacy
		Licensee obtains adequate short-term sureties to provide for closure
20-40 yrs	License Issued; Site is in Active Operation; Waste Received	Short-term sureties in place for closure: NRC periodically reviews and requires updating to account for changes in inflation, site conditions, etc.
		NRC periodically reviews revisions to lease arrangements to ensure that arrangements for financial responsibilities for long-term care are adequate
1-2 yrs	Site Closure and Stabilization	Costs covered from short-term sureties, if necessary; otherwise, licensee performs activities
		Lease arrangement between site owner and operator for long-term care is still in effect
5-15 yrs	Observation and Maintenance	Licensee still responsible for all further costs during this period, with short-term assurances still in place
100 yrs	License Transferred to Site Owner; "Active Institutional Control Period"	Terms and conditions of lease are met, and either state or licensee provides funds to pay for all required and necessary activities of this period

adequate financial resources for closure, contingencies, postclosure care, and institutional control could have prevented this from happening.

As discussed in the review of the operating histories of low-level waste disposal sites in Appendix K of the EIS, the necessary closure and long-term care activities have, in some cases, not been undertaken, or have had to be conducted by the state government, because of the lack of planning for and lack of financial assurances for such activities. Closure, postclosure, and active institutional care costs are generally incurred after the site operator is no longer receiving revenues from waste generators. Thus, proper planning during the operating phase when revenues can be accrued is essential.

Based on these considerations, there is a strong need for regulatory requirements to ensure that: (1) the licensee has sufficient financial resources to provide for final closure and postclosure care of the site, and (2) the licensee provides financial assurance for the active institutional control period after the site is closed and stabilized. The staff believes these closure and active institutional care costs should be identified early and should be provided for as part of the necessary costs of operating a site. Financial assurance mechanisms to provide for these costs should be established during the active operating period of the site, when revenues are still being received by the licensee, and he has access to financial resources. An applicant seeking a license for the disposal of low-level waste must estimate the costs of closure in order to provide for adequate financial assurances based on these estimates. Therefore, the amount of financial responsibility required of licensees will be consistent with the degree of risk associated with the closure and active institutional care of the site. (Estimates of the costs of various potential expenses of closure and postclosure care of a site are presented in Appendix Q of the EIS.)

Meeting such a technical requirement for closure and active institutional care will involve a cost to the licensee. However, proper closure should help to prevent other costs, such as remedial costs, administrative costs to the regulatory agency, and environmental costs. For example, failure to provide for adequate financial assurances for closure could result in a situation where it is necessary for the responsible regulatory agency or the site owner to provide for final closure and stabilization at taxpayer expense. Any corrective actions would also need to be taken by the agency as well as the longer term institutional control activities. Environmental costs that could be incurred if a licensee was unable to conduct final closure and stabilization could include increased potential for contamination of soil, air, and surface and ground waters. Adequate funds must be provided during operations to cover the costs for closure and for long-term care activities.

The need for stringent financial requirements to ensure that the licensee is financially responsible has been voiced by a number of sources, including the U.S. General Accounting Office, the National Conference of Radiation Control Program Director's Task Force on Bonding, numerous state officials, and also in public comments received on the preliminary draft regulation for low-level waste disposal. These comments, along with the federal and state regulatory precedents described in Appendix K have enabled the staff to examine a range of alternatives for financial assurances.

9.2.1 Federal and State Precedents for Closure, Postclosure, and Long-Term Care Requirements

In developing requirements for financial assurances for closure and postclosure and for long-term care, the NRC staff examined federal and state regulatory requirements. These other regulatory requirements not only provided precedents for the NRC regulations, but also enabled the staff to examine a range of financial assurance instruments. Furthermore, the experiences gained by the various agencies in administering these various mechanisms also enabled the staff to evaluate the administrative time required to implement them.

9.2.1.1 Federal Financial Assurance Mechanisms

9.2.1.1.1 Environmental Protection Agency (EPA)

The EPA is currently engaged in drafting financial protection regulations for operators engaged in the disposal of hazardous waste. Under the Resource Conservation and Recovery Act (RCRA), the EPA is required to establish financial responsibility standards applicable to owners and operators of hazardous waste management facilities. EPA concluded that financial responsibility performance standards are necessary to assure that funds will be available for the proper closure and postclosure care of the site. The interim final rules issued January 12, 1981 require the owner or operator of each hazardous waste treatment, storage, or disposal facility to establish financial assurances for closure and for postclosure care. Acceptable financial assurance mechanisms include trust funds, surety bonds, letters of credit, or a combination of these mechanisms.

9.2.1.1.2 U.S. Department of the Interior, Office of Surface Mining

The Interior Department issued regulations in 1979, pursuant to the 1977 Surface Mining Control and Reclamation Act, requiring operators of surface mining operations to obtain a performance bond to assure that the area will be managed in accordance with performance standards. Performance bonds include surety bonds, collateral bonds, escrow accounts, self-bonds, or a combination of these financial assurance mechanisms.

Collateral bonds may be supported by cash, certain negotiable bonds, certificates of deposits, irrevocable letters of credit, or a mortgage or security interest in property granted to the regulatory authority equal in value to the bond obligation. Companies may self-insure if they can show financial solvency and continuous operation for ten years.

9.2.1.1.3 Federal Maritime Commission (FMC)

The FMC has responsibility under several water pollution control acts for issuing and implementing regulations to require vessel operators to provide financial protection to ensure that they will be able to meet potential obligations arising from spills. The regulations allow the following methods: (1) insurance, (2) surety bonds, (3) self-insurance, based on the operator maintaining certain specified levels of net worth and working capital, (4) a guarantee where the guaranteer meets the self-insurance requirements, and (5) other evidence of financial responsibility.

9.2.1.2 State Financial Assurance Mechanisms

9.2.1.2.1 Illinois

U.S. Ecology, Inc. (formerly, The Nuclear Engineering Company, Inc.) operated a low-level waste disposal site at Sheffield, Illinois which is now closed. Financial arrangements for "perpetual care" are found in a lease arrangement signed between the site operator and the state. The original terms of the lease called for the operator to pay the state $0.05 for each cubic foot deposited at the site. However, at the time that the lease was executed, the state did not have an earmarked or state fund for the collection of these fees. Funds collected for care and maintenance prior to October 1976 were deposited into the general treasury of the state, and are not now available for closure and for postclosure care. In 1978, the lease was amended so that the operators had to pay into a state perpetual care and maintenance fund in the amount of $0.10 per cubic foot. The Illinois General Assembly also recognized that sites used for the disposal of radioactive waste would represent a continuing and perpetual responsibility in the interest of health, safety and general welfare. Fees collected after September 1976 were deposited in the state treasury and set apart in a special fund known as the Radioactive Waste Site Perpetual Care Fund. Monies from the invested funds were to be used by the Director of the Department of Public Health to monitor and maintain the site. However, as of December 1979, there was only approximately $50,000 in the fund, which state officials found to be insufficient for the purposes of any long-term care activities at the site.

9.2.1.2.2 Nevada

U.S. Ecology, Inc. operates a low-level waste disposal site at Beatty, Nevada and has collected funds for closure and for long-term care. A lease arrangement was set up originally, whereby the company agreed to collect a fee from waste generators who use the site. However, by 1976, state officials indicated to NRC staff that their earlier provisions for long-term care funds for the site were inadequate. Recently however, the state has taken measures to ensure that a larger amount of funds are available for closure and for postclosure activities. In 1977, the state enacted legislation which revised the radiation protection regulations as well as calling for the development of a long-term care fund for the radioactive disposal site. The legislation created a Radioactive Materials Disposal Fund in the state treasury. Fees collected from waste generators by the licensee are to be deposited into the fund and subsequently invested.

9.2.1.2.3 South Carolina

Chem-Nuclear Systems, Inc. operates a low-level waste disposal site at Barnwell, South Carolina. The company and the state of South Carolina are parties to a lease requiring the company to pay the state a cubic foot charge for long-term care of the site. The lease calls for increases in the amount of the surcharge every three years in accordance with changes in the Consumer Price Index. The escrow account into which the fees are deposited for long-term care continues to be maintained, and interest is earned on the monies accrued to the fund.

In May 1980, the company also submitted a draft trust fund arrangement to South Carolina to handle the collection of closure expenses as part of their preliminary site stabilization and closure plan for the site. The terms of the draft trust, which are currently being negotiated with the state, call for the company to transfer the collected surcharges to the trust fund, until a total of $1,000,000 is collected.

9.2.1.2.4 Kentucky

U.S. Ecology, Inc. operated a low-level waste disposal site at Maxey Flats, Kentucky which is now closed. In 1976, the Kentucky General Assembly passed an act that imposed an excise tax of $0.10 per pound on all radioactive materials delivered in the state for processing, packaging, storage, and disposal. A study prepared for the Kentucky legislature recommended that the monies from the surcharge should be placed in a special escrow account for long-term care and maintenance, rather than in the general fund, as had previously been the case. Additionally, NRC discussions with state officials indicated that there were insufficient funds available to pay for necessary closure and remedial activities. After the $0.10 surcharge became law on June 19, 1976, the quantity of nuclear waste disposed of at Maxey Flats declined by 95%. The site was closed in 1977, by order of the state, pending the completion of a water management program. Discussions with state officials indicate that insufficient funds were available from the Maxey Flats long-term care fund to provide for closure or long-term care activities.

9.2.1.2.5 Washington

U.S. Ecology also operates a low-level disposal site at Hanford, Washington. The state and NECO were both parties to a lease arrangement requiring the development of a long-term care fund, which consisted of fees collected from waste generators. Funds in the long-term care fund are invested by the State Finance Committee in the same manner as other state monies, and any interest accruing as a result of investment is returned to the fund. Since 1980, these funds have been collected on the basis of a $.25 per cubic foot surcharge levied on waste generators using the site.

9.2.1.2.6 New York

Nuclear Fuel Services (NFS) established a low-level waste burial ground at West Valley, New York in 1962. Under the terms and conditions of a lease negotiated between NFS and the state, NFS was required to maintain and provide storage and maintenance of the wastes before returning control to the state. NFS was also required to collect and turn over to the state or federal government at the point of closure a charge calculated to provide the estimated full costs for perpetual storage. In the 1970s, the low-level waste burial ground was closed. State government officials indicated that insufficient revenues were available to provide for maintenance at the site, and this issue has not been resolved.

9.2.1.2.7 Oregon

Oregon requires owners or operators to submit a closure and postclosure plan as part of a facility permit application. The state reviews each plan and then estimates closure and postclosure care costs at the site. The state then requires each owner or operator to obtain a cash bond in the name of the state to cover closure and postclosure costs.

9.2.1.2.8 Wisconsin

Wisconsin requires hazardous waste facility operators and owners to submit a closure and postclosure plan. The state allows the owner or operator to provide proper closure and postclosure care. The owner or operator must set aside all necessary funds to close his facility before he may begin facility operations. However, payments may be made into the postclosure fund at regular intervals during the life of the site. The owner or operator is financially responsible for long-term care of his site for either 20 or 30 years after closure, when the state then assumes responsibility. The State Waste Management fund is also used to pay for costs of long-term care of a site occurring after the responsibility of the owner or operator has ended.

9.2.1.2.9 Kansas

The state of Kansas passed an act in 1979, that authorized the establishment of fees for monitoring hazardous waste storage sites, paying extraordinary costs, monitoring after site closure, payment of maintenance expenses, and repairs for environmental damage at a site. Kansas also requires hazardous waste facility owners or operators to submit a closure and postclosure care plan. Owners or operators are responsible for care of a site for 10 years after closure. Kansas requires a trust fund or performance bond to assure compliance with facility closure and monitoring requirements. In lieu of a trust or surety bond, the state will accept a deposit by the owner or operator of cash or U.S. Treasury notes to the State Treasury or to an escrow agent deemed satisfactory by the state.

9.2.1.2.10 Maryland

Maryland hazardous waste regulations require owners to demonstrate evidence of financial ability to provide closure and postclosure care of a hazardous waste management facility. The owner or operator must obtain a surety bond in an amount specified by the state, or transfer ownership or operation of the site prior to closure. The surety bond must cover any costs of monitoring, maintaining, and closing a facility, ensuring the security of a facility after its closure and guaranteeing fulfillment of all permit requirements.

9.3 FINANCIAL ASSURANCES FOR CLOSURE AND POSTCLOSURE CARE OF A LOW-LEVEL WASTE SITE

This section presents the staff's development of technical requirements for financial assurances for closure, stabilization, and postclosure observation and maintenance activities at a low-level waste disposal site.

9.3.1 Introduction

After a typical low-level waste disposal site has been filled to capacity, the site owner is no longer receiving commercial revenues from the receipt and disposal of waste. However, even though he is no longer receiving revenues to operate the site, the licensee is still responsible for a variety of the site expenses, such as closure, stabilization, and postclosure observation and maintenance of the site. As discussed earlier, the experiences at LLW and other hazardous waste sites serves to indicate that there is a strong need for a regulatory mechanism to ensure that financial responsibility for closure be established at an early stage of site operations, so that sufficient resources are available for later closure activities. The staff believes low-level waste licenses should demonstrate financial assurances sufficient to provide for the full costs of all closure and postclosure care activities. (For a typical reference near-surface disposal facility, these closure costs are estimated by the staff to be in the range of $1.0 to $3.0 million, in constant 1980 dollars. See Appendix Q for a detailed breakout of estimated closure costs.)

9.3.2 Technical Requirements for Financial Assurances for Closure and Postclosure

Short-term financial assurance mechanisms refer to arrangements intended to ensure that the licensee is financially responsible for undertaking required decommissioning, closure, stabilization, and postclosure activities at a low-level waste site. In these arrangements, the concept of financial assurances does not include any requirements for third party liability coverage for damages to people or property resulting from operation of the facilities. Rather, the staff is establishing various financial assurance requirements which will ensure that the sites are properly closed, stabilized and monitored for up to 100 years. These activities would include closure and stabilization of the low-level waste site according to license requirements and regulations, and be particularly based on the site closure and stabilization plan. The need for ensuring financial responsibility for closure is based on the realization that a situation might occur where financial resources for closure are inadequate, causing the government to have to assume responsibility for closure costs. If no financial arrangements have been made, then the government would have to assume responsibility for the costs of closure in the event of licensee default.

Based on a review of previous experiences, the staff developed the following technical requirements for operators of a disposal facility:

- Each applicant must demonstrate adequate financial resources to cover the estimated costs of conducting all licensed activities over the planned life of the project including ensuring that sufficient funds will be available to carry out final site closure, postclosure care and stabilization activities.

- Prior to startup of operations, the licensee must obtain a short-term financial assurance mechanism found acceptable to the Commission that is sufficient at all times to cover all costs of closure, and postclosure care and must be based on a Commission approved plan for site closure and stabilization.

- The financial assurance mechanism must be full funded prior to the start of operation, to provide full assurance regardless of whether closure occurs as was originally planned, or occurs prematurely.

- o The short-term mechanism must be in effect throughout the operating period of the site.

- o The face value of the short-term financial assurances must be at least equal to the cost estimates submitted by the licensee in the approved plan for site closure and stabilization.

- o The licensee's cost estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the decommissioning and closure activities.

- o The license may use one or more financial assurance mechanisms to meet these requirements.

- o The financial assurance mechanism must be open-ended and cannot be cancellable.

- o Proof of forfeiture must not be necessary in order to collect the financial assurance mechanisms. If the licensee cannot provide an acceptable financial assurance substitute within the required period, then the original mechanism will be automatically collected prior to its expiration.

- o The Commission will allow the licensee to terminate the financial assurance mechanism after a finding that all license conditions have been met.

- o The adequacy of the amount of funds provided by the financial assurance mechanism to account for changes in inflation, site conditions, and technology will be reviewed annually.

The staff's development of these technical criteria for financial assurances for closure was based on recognition of the importance of balancing the need to require sufficiently stringent assurances with the economic consequences of the alternative. For example, in developing criteria that the financial assurance mechanism must be fully funded prior to start up of operations, the staff also considered the less stringent approach of allowing the funds to build up over the life of the site. The staff was aware that this second approach would have been a lesser financial burden to the operators, since it would not require them to set aside a large sum of capital. (In their development of RCRA regulations, the EPA also noted that the fully funded approach placed a tax burden on the operator, because current tax laws do not allow this fund to be considered a deductible expense; since no expense occurs in a tax sense until the funds are used for closure.) Nevertheless, the staff also realized that allowing a closure fund to build up over the life of the site could well result in having an inadequate fund available in the event of premature closure of the site, with the result being that the taxpayers would then be financially responsible. In weighing these two equity alternatives, the staff concluded that the fully funded approach to closure offered the most reasonable assurance that the licensee be fully responsible for the costs of closure.

9.3.3 Alternative Financial Assurance Mechanisms for Closure Considered by the Staff

There are a variety of short-term financial assurance mechanisms that could be used by a low-level waste operator to assure that sufficient funds are available for closure and postclosure care. Short-term financial assurance mechanisms considered by the staff include the following:

1. Surety bonds, obtained from a surety company;
2. Escrow arrangements between the bank, the government, and the licensee;
3. Trust funds, arranged between the government, a financial institution, and the licensee;
4. Certificates of deposit to a state or federal agency;
5. Cash deposits to a state or federal agency;
6. Deposits of securities to a state or federal agency;
7. Secured interests in the disposal operator's assets;
8. Letters of Credit from a financial institution;
9. Self-insurance by the low-level waste disposal operator;
10. Financial tests of the operator or his holding company;
11. Development of a sinking fund based on receipts from capacity surcharges.
12. Development of a closure assurance pool.

These types of financial assurances are standard commerical law arrangements being used by state and federal government agencies for the chemical waste, uranium milling, low-level waste, and surface coal mining industries. The staff considers these alternatives to be reasonable possibilities for consideration in this rule.

Each alternative was evaluated based upon a specific set of criteria. The primary factor considered by the staff in evaluating these alternative financial mechanisms was the degree of assurance provided by each method to ensure that funds were available for closure costs at the disposal site to provide for all necessary activities to protect the public's health and safety. Other criteria considered by the staff included the following:

- Degree of security (or level of difficulty) in obtaining funds in case of default.

- o Amount of administrative time and expense of the regulatory agency required to implement and monitor the financial assurance mechanisms.

- o Cost of utilizing the financial assurance mechanism to the licensee.

The staff's review of the various financial alternatives is presented below, and discussed in greater detail in Appendix K.

9.3.3.1 Surety Bonds

A surety bond provides a cosigner on an obligation. The bond is essentially a contract among three parties, whereby the surety company promises to the obligee (the NRC) that the principal (the licensee) will perform specified closure activities. The surety company takes on a possible liability for a profit. The surety company will seek some sort of collateral from the principal, and the amount will vary depending on the financial conditions of the principal and other factors. The cost of a surety bond is dependent on the type of required activities covered by the bond, but fees or premiums generally range from between 1.0 and 1.5 percent of the face value of the bond. If a licensee with a surety bond were to become bankrupt, then the bonding company would provide the amount of the surety for all obligated closure costs.

The surety company also needs to have sufficient assets to provide for possible default. Surety companies have the option of filing with the U.S. Treasury, which sets limits on the face values of bonds. Since filing with the Treasury provides a form of certification, the Commission staff feels that surety bonds should only be accepted for the purposes of 10 CFR Part 61 if they are on the list of accepted companies listed in the Treasury Department's Circular #570, entitled "Surety Companies Acceptable on Federal Bonds", and only for an amount that is within the company's single policy limitation as identified.

Surety companies are generally regulated by state laws that are designed to ensure that the surety company is solvent and has assets of a certain minimum amount. Additionally, state regulation of sureties involves assessments of financial management practices, including examination of whether the sureties are diversified in their lines of credit. This review by state agencies, as well as the review conducted by the Treasury Department prior to issuance of Circular #570 give the regulatory agency concerned with closure of the site additional confidence that the surety company will be capable of paying in the event of default by the licensee.

The agency's administrative effort in monitoring a surety bond for the regulatory agency would not be significant. The regulatory agency would only have to periodically review the amount of the surety bond, to determine that there were sufficient resources to provide for changes in inflation, or site conditions.

A major problem with surety bonds is their availability. Staff discussions with surety company officials indicated that there may not be any companies willing to provide surety bonds because of their open-ended nature and the potentially long time period. However, staff decided to recommend the use of a surety bond for a financial assurance mechanism because the bonds may be available in the future.

9.3.3.2 Cash Deposits into a Government Account

A cash deposit is another method of assuring financial responsibility for closure. An amount at least equal to the estimated cost of closure is deposited into a special account that could be held by a state or federal government agency. Use of the funds in this account would be restricted to covering the costs of closure and stabilization of the site. If the operator were to default, then the state or federal government could withdraw the funds from the special account and arrange for the necessary closure work to be completed at the site. The funds would have to be put into an earmarked fund and not deposited into the general treasury so that the funds are specifically retained to provide for the purpose they were intended for. The funds should also be invested in a prudent manner so that the face value increases to keep pace with changes in inflation.

The staff considers that use of a cash deposit by a licensee as a financial assurance mechanism for closure would be a secure method of ensuring that funds were available for closure. However, this method would result in a large loss of productive assets of the licensee, as he would have to put up the full face value of the costs of closure. This method would also entail some degree of administrative responsibility by the regulatory agency. The agency staff would have to periodically examine the amount in the special fund in order to ensure that the funds were invested properly, and that they were keeping pace with inflation.

9.3.3.3 Escrow Accounts

An escrow account can also be used to assure funds for closure and for decommissioning. Under such an agreement, cash or marketable securities in an amount equal to or greater than the estimated costs of closure are deposited into a special account held by a financial institution. An escrow account serves as a receptacle for the deposit of goods or property until such time as the licensee completes the required closure activities. The institution holding the assets is the depository and an escrow agreement is necessary to set out the terms and conditions by which the materials can pass to either party.

Depositors however, are not trustees. An escrow agreement involves a binding agreement with terms and conditions specifying that upon failure of the licensee to meet the prescribed closure activities, the fixed amount necessary for all closure activities held in escrow would pass to the appropriate state or federal government agency. Conversely, upon a finding that closure had been satisfactorily conducted, the escrow agreement would be terminated and the amount in the escrow returned to the licensee.

Generally, administrative fees are charged for the management of an escrow account and will vary depending on the degree of activities, not on the amount of funds. One of the big differences between a trust and an escrow account occurs because a bank managing an escrow account generally will only perform those activities specified in the agreement. As with all other types of financial assurance arrangements, the types of investments made by the supervisory personal of the escrow would entail some administrative cost to the regulatory agency, in order for them to be assured that the funds were keeping pace with inflation. However, there would be little problem with asset valuation for the regulatory agency, since the financial institution would take that responsibility.

9.3.3.4 Trust Funds

A trust fund is a mechanism for holding property and applying it or income from it to a particular purpose. The concept of using a trust fund to provide for financial assurances for closing a waste disposal facility is not new. In 1980, a trust fund to provide for decommissioning and closure costs was proposed by Chem-Nuclear Systems, Inc., for their Barnwell, South Carolina LLW disposal site. The RCRA financial requirements being developed by the U.S. Environmental Protection Agency for hazardous waste sites have also recognized the trust mechanism as an acceptable type of financial assurance for closure.

A trust fund is a financial arrangement whereby one party holds and may even manage funds or property for the benefit of another. In this case, the beneficiary of the trust fund would be the state or federal government. The trustee of the closure trust would be a bank or financial institution. The terms of the trust would define the investment responsibilities of the trust. The trustee has possession of the property, or funds placed in trust by the party who created the trust (in this case, the state or federal government). The trustee is said to have the legal interest in the fund since he has control over it, can sue to protect it, and is responsible for its preservation. The beneficiary cannot use the trust funds, but is entitled to those benefits, (such as income) derived from the trust, and intended for him under the terms of the trust. The trustees are under a fiduciary duty to comply with the terms of the trust, and unless the trust provides otherwise, are liable for breaches of this duty.

A trust fund can contain more than just cash. Property such as securities or government notes can be placed in trusts. However, if cash substitutes are allowed within the framework of trusts, then the function and obligation of the trustee must be redefined, and they may possibly charge more for their services. If other types of assets are allowed, the trust would have to agree to pay the NRC or some other federal agency a stipulated cash amount. Additionally, if assets other than cash are deposited into the trust fund, it may be necessary for the trustee to buy and sell securities with the approval of the regulatory staff, or take other steps to manage the assets in order to maximize their value. However, unless specified in the terms of the trust, a trustee usually must invest under a reasonably prudent investor standard as defined by statute or case law of the jurisdiction where the trust is located. The trustee has a fiduciary obligation to honor the terms of the trust, and this standard of fiduciary duty is so strict that most trustees will only accept carefully defined responsibilities.

Trustee fees may be relatively constant, but are normally defined as a percentage of income; generally trustee funds may range from between 1% and 2% annually of the amount to be managed in the trust.

Trust funds provide a high degree of security that funds will be available for closure. They also do not place a significant administrative burden on the regulatory staff. This form of financial assurance mechanism also provides a productive use of assets, as the monies in the trust fund are managed by fiduciaries with expertise in investing.

9.3.3.5 Certificates of Deposit

Another financial assurance mechanism that the staff reviewed for assuring closure activities at a low-level waste disposal site is Certificates of Deposit (CDs). Generally, CDs may be issued by any bank. Cash or securities are deposited by the site owner with the bank, and a certificate is issued, made payable to a government agency. Only the government agency could cash the certificates. The CD would then be cashed by the regulatory agency if the operator was unable to complete decommissioning and closure activities. Again, as with all forms of financial assurance, the CD would be adjusted over time to reflect inflation. At the end of operations, if the operator satisfactorily closed the site, then the government agency would return the CD to the site operator.

A CD provides a high degree of security that sufficient funds will be available for closure activities. Certificates are a financial assurance mechanism that requires little effort by the regulatory agency staff except to periodically monitor the CD to ensure that the face amount is adjusted to reflect changes in inflation, technology, and site conditions.

9.3.3.6 Deposits of Securities

Using this financial assurance mechanism, the licensee would be responsible for depositing securities to the appropriate government agency with a face value equal to or greater than the highest cost of closure at the site. Theoretically, the securities could be of several different types, including long-term U.S. bonds, municipal bonds, or corporate securities. This mechanism could place a significant administrative burden on the regulatory staff because they would have to monitor and review the securities to ensure that inflation was not eroding the value of these securities. The staff plans to provide further guidance on the types of acceptable securities in a regulatory guide to be published later.

9.3.3.7 Pledges of Securities and Liens Against Property of the Operator (Secured Assets)

These financial assurance mechanisms are similar to self-insurance, except that the licensee pledges certain assets which could be used by the Commission to perform closure activities in the event of licensee default.

A secured interest is an interest in personal property or fixtures of the operator that gives to the holder of the interest, rights to possession of the property to ensure payment of an obligation. A secured interest payable to a government agency gives that government agency the right, in the event of default by an operator, to take possesion of the assets it has an interest in, and sell them in satisfaction of the claim. In most cases where a secured interest has been properly created, the holder of the interests has first claim or priority over these assets in the event of licensee bankruptcy.

Secured interests have the particular advantage to the operator of involving few additional expenses. The only costs involved would be those legal costs associated with preparing the documents. However this financial assurance mechanism poses significant disadvantages for the regulatory agency. From a regulatory standpoint, the use of secured assets does not offer as stringent a degree of protection in the event of licensee default. Substantial problems will occur if the government must obtain assets in the event of default. Other creditors may place a lien on the company's assets, and the legal process may considerably delay recovery of the assets, thus necessitating legal proceedings. Another regulatory disadvantage of this financial assurance mechanism is the amount of time necessary for administration.

The regulatory staff would have to spend a significant amount of time evaluating the assets of the operator, and this review would have to be done on a periodic basis in order to account for changes in inflation, depreciation, etc. And finally, if the government did receive title to the assets of the operator in the event of licensee default, the government would have to undertake the task of disposing of the secured assets.

An Environmental Protection Agency review of this financial assurance mechanism has also found that liens suffer from an uncertain status in the event of financial failure of the operator.

9.3.3.8 Letters of Credit

Letters of credit are another short-term financial assurance mechanism investigated by the staff for the purposes of ensuring that sufficient funds are available for closure and postclosure care. The operator would apply to a bank for the issuance of a letter of credit that commits the bank to pay the beneficiary (the state or federal government) if the letter of credit comes due. A letter of credit consists of a bank's document written on behalf of the operator that would give the government agency the right to draw funds from the issuing bank upon the presentation of papers in accordance with the letters of credit. The guidelines for a letter of credit are found in the U.S. Treasury regulations. A national bank can issue letters of credit permissible under the Uniform Commercial Code on behalf of its customers.

An acceptable letter of credit for the purposes of this regulation would be to specify the NRC or some other governmental agency as the party who may draw upon the fund in the amount of the most recent closure care estimate required to be made by the regulations. The letter of credit should specify that the regulatory agency can draw upon the funds behind the letter of credit, following the finding of a violation of the closure requirements.

Fees for issuing a letter of credit are generally lower than those for trusts or bonds. The cost of a letter of credit is based on the face value of the amount. This financial assurance mechanism is advantageous to the regulatory agency because it requires only a minimal amount of time to administer. There is also no problem of having to evaluate assets, since this activity is performed by the bank.

9.3.3.9 Self-Insurance by the Operator

As used in this analysis, self-insurance refers to an arrangement whereby the operator agrees to perform all closure and postclosure activities, and to finance the activities out of his own resources, such as cash working capital. In effect, it is an alternative involving no additional assurances other than the licensee's legal obligation to perform closure activities required by the regulation and as a condition of license. The legal obligation will exist regardless of any separate contract or lease.

The main problem for a regulatory agency contemplating self-insurance for a financial assurance mechanism is that there is no guarantee that the licensee will actually perform the closure activities. The licensee may not have sufficient funds to meet their license responsibilities and if this is the case, there is no special leverage that the regulatory agency can use to obtain the funds from the licensee. In case of default, the government agency would have to obtain a legal judgment based on its license contract with the licensee, and then would have to execute its judgment if the operator has assets out of which the judgment can be satisfied. This approach provides no assurances that sufficient funds will be available for closure.

9.3.3.10 Financial Tests

Financial tests are another variation on self-insurance, which have been used as a financial assurance mechanism by several other state and federal regulatory agencies. A financial test involves having the regulatory agency develop a set of criteria which shows that a licensee has sufficient unencumbered assets. The assets are not pledged or retained for closure. Rather financial tests would enable the Commission to monitor the financial health of the licensee's operations, and in the event of a deteriorating financial condition, the licensee would be required to establish another method of financial assurance.

There are a variety of financial tests which could be used by regulatory staff to ascertain that the licensee has sufficient financial health: net working capital, net worth, a review of the total liability to net worth ratio, current or quick ratio, and the age of the firm. The reader is referred to Appendix K of the EIS for a description of these financial tests.

While advantageous to the operator, the use of financial tests provides no degree of financial assurance that the licensee will have sufficient unencumbered assets to provide for closure. Additionally, the use of financial tests involves an inordinate amount of administrative time and effort by the regulatory staff, who must periodically review the financial information to verify that the operator has sufficient assets to provide for closure of the site.

9.3.3.11 No Financial Assurance Requirements for Closure and Postclosure

Another regulatory alternative for short-term care would be for the regulatory agency to not establish any funding requirement on waste licensees for financial responsibility for closure. With such a scenario, the custodial care regulatory agency or the site owner could be responsible for all costs incurred during closure and postclosure. Additionally, the staff did not consider this alternative for long-term care, since some form of financial assurance for closure and long-term care are already being implemented at existing LLW disposal sites. The Commission staff has also received comments on the need to establish financial responsibility for short-term closure and postclosure care activities of low-level waste sites.

Based on these findings, the staff has determined that a regulatory approach of not requiring short-term financial assurances for closure of a site is not acceptable.

9.3.3.12 Other Short-Term Sureties

9.3.3.12.1 Imposing a Surcharge on Waste Generators and Depositing Funds into a Sinking Fund

In the past, state regulatory authorities have frequently required operators of low-level waste disposal sites to impose a surcharge on a cubic foot or meter basis on the site's users, to recover some degree of closure and post-closure expenses. In a petition for rulemaking, the Natural Resources Defense Council also requested that a surcharge on a capacity basis be imposed on users of disposal sites. The staff recognizes the merit of such an approach from a regulatory standpoint. The use of a surcharge deposited into a sinking fund has been used as a collection method by several state regulatory agencies. The use of a surcharge also is an equitable system of providing for closure costs, because the responsibility for these costs is borne by the waste generators who use the waste disposal service. Nevertheless, there are several problems with the use of this financial assurance mechanism. First, a sinking fund builds up funds gradually over the life of the site, and therefore, the fund will not have sufficient assets during the early portion of its inception to account for the full costs of closure. Such a mechanism would not guarantee that the full costs of closure were available at all times to account for closure. (This problem could possibly be alleviated by simultaneously requiring another financial assurance mechanism on the balance of the closure funds.) A second reason why this financial assurance mechanism is not appropriate is because the NRC currently lacks the statutory authority to require a surcharge or a fee per unit volume of waste. Establishment of an earmarked fund would also require Congressional authorization. In 1978, the NRC staff responded to a petition for rulemaking by the Natural Resources Defense Council, that called for NRC establishment of a special fund based upon a cubic foot surcharge. In their response to the petition, the staff noted that a federally mandated fee per unit volume of waste that is not a product of the landlord/tenant contract (i.e., a lease) would be, in essence, a tax that requires legislative enactment. Based on landlord/tenant (state or federal government/site operator) contracts authorized by state law, the states containing commercial burial sites have collected disposal fees from the site operator on a capacity basis. However, for the reasons stated above, a financial assurance requirement consisting of a surcharge as a means of collection cannot be imposed at the federal level.

9.3.3.12.2 Closure Pool

Another possible variation for assuring adequate financial funds for closure involves the development of a pool of closure assurance funds. Disposal facility operators (and possibly, operators of other fuel cycle facilities) would make payments to such a fund. An independent "Closure Assurance Agency" would be chartered to retain and invest the funds, and perhaps oversee activities and disperse payments to those conducting the activities. The pooling of funds into such a shared risk centralized agency could help to ensure closure even if a particular facility operator defaults. The agency would act in a fiduciary capacity for the public. Payments and interest received by the stewardship entity would possibly be exempt from federal income taxes, because the entity would be a creation of the U.S. or a state government and an exempt scientific entity.

The pool would be obligated to pay for closure of a site if the operator defaulted on performance of required closure activities. However, setting the appropriate premiums would be difficult, since the pool administrator would have to estimate the likelihood of nonperformance or partial performance, and then calculate the magnitude of the fund required to complete the closure. Such a pool would probably have to be established by the federal government and would require Congressional action.

9.3.4 Conclusions and Financial Assurance Mechanisms for Closure and Postclosure Found Acceptable by the Staff

Given the past history at some of the existing disposal sites, one of the key concerns is assurance of adequate financial qualification on the part of the applicant to construct and operate the disposal facility and to provide adequate financial provisions for disposal site closure and postoperational activities. The staff believes the applicant should be financially qualified to conduct all license activities during the construction and operational phases of the land disposal facility. Proof of the financial qualifications of applicants is not currently required by Parts 30 and 40. This new requirement will help assure that resources are not expended on projects without adequate backing. This requirement should minimize the potential for early default or the abandonment of the site by the operator.

Given the past history, the staff also concluded that the facility operator should provide financial assurances for closure and postclosure care. A requirement for financial assurance for closure can be viewed as a type of financial guarantee to ensure that in the event of operator default, there are funds available for closure. The NRC received evidence of a great deal of public interest concerning the issue of financial responsibility for closure of a disposal site. Numerous written comments were made on this portion of the draft regulation, and the issue was also raised at all four workshops held to review this regulation. Many commenters felt that the licensee should be held responsible for the full costs of closure of a disposal site and that the license should not be terminated and the land returned to the custodial government authority until the licensee has completed satisfactory closure.

The amount of surety liability required should be based on cost estimates submitted by the licensee in an approved plan for disposal site closure and stabilization. The applicant must submit a cost estimate for disposal site closure that includes consideration of inflation, increases in the amount of disturbed land, and the closure and stabilization activities that have already occurred at the disposal site.

Based on the review of the alternative financial assurance mechanisms, the staff found a variety of financial assurance mechanisms acceptable. The decision to select specific alternatives was based on the degree to which the various mechanisms conformed to the technical requirements previously listed in this chapter. Additionally, consideration was given to the views and experiences of other regulatory agency staff with experience in administering these various financial assurance mechanisms.

The staff concluded that a number of financial assurance mechanisms exist that will provide adequate public protection to ensure that funds for closure and postclosure exist in the event that the site operator defaults or unforeseen site conditions require early closure of the site. The alternatives that the staff finds acceptable on a generic basis for a disposal facility licensee are:

- surety bonds
- trust funds
- escrow arrangements
- cash deposits
- certificates of deposit
- deposits of government securities
- irrevocable letters of credit
- combinations of the above

These alternatives were all found to be acceptable by the staff because they didn't impose a significant economic burden on the license, they didn't impose an administrative burden on the staff, and yet they each could be structured to ensure a high degree of confidence that funds would be available to ensure proper closure. The staff also has concluded that approving a range of satisfactory financial assurance alternatives allows the operator flexibility in selecting the mechanism that best suits his needs. While the other financial assurance mechanisms discussed earlier may be acceptable in certain isolated cases, they are not acceptable to the staff on a generic basis. Plans for alternative financial assurance mechanisms not discussed here would be evaluated and approved by the staff on a case-by-case basis. The costs for short-term financial assurances have been included as part of the costs for the reference facility described in Apppendix E.

9.4 LONG-TERM CARE (ACTIVE INSTITUTIONAL CONTROL PERIOD) FUNDING REQUIREMENTS

9.4.1 Introduction

Based on a review of the operating history at existing LLW disposal sites, the the staff finds that financial responsibility for long-term care (active institutional control) should be established throughout the operational life of the disposal facility. Financial assurances for active institutional control involve the financing of any required activities at a low-level waste site after completion of closure and postclosure care activities. These funding assurances would cover surveillance, monitoring, and any necessary maintenance to assure that the stability and integrity of the site is maintained and that there are no disruptive human activities at the site for up to 100 years.

9.4.2 Need for Requiring Financial Assurances for the Active Institutional Control Period

A review of the history of commercial low-level waste sites in this country indicates that there has been continuing concern by the public and by regulatory authorities over long-term financial responsibility for low-level waste disposal sites. In addition to questions over the equity issues of who pays for active institutional control over the site, the government and the public are concerned that funds be readily available for such postoperational activities in order to ensure that the public's health and safety are continually protected. The controversy over postclosure control at the Sheffield, Illinois low-level waste disposal site is a contemporary illustration of the dilemma that exists in this area. Another event that has highlighted this controversy concerning the adequacy of long-term care funds occurred at the closing of the low-level waste disposal site at West Valley, New York. A report done by the U.S. General Accounting Office also found that the financial responsibility for this site raised larger policy issues "concerning whether or not, and to what extent, the federal government should provide financial assistance to the nuclear industry by taking over the cost of managing activities in the back end of the fuel cycle." Based on these considerations, the Commission staff concluded that requirements for financial guarantees for active institutional control should be included in the proposed low-level waste regulations in order to ensure that the public's health and safety are protected.

Existing state financial requirements for long-term care of a disposal site have frequently been referred to as "perpetual care arrangements." They are based on the same concept as scholarships, research endowment funds, or perpetual care funds for cemeteries. Funds are invested and a return is earned on this principal. When this amount of interest earned is adjusted by the annual inflation rate, the net rate of return is determined. If a sufficient return is earned, it is then used to pay for various activities, such as research, scholarships, maintenance at the cemetery, or conversely, surveillance, monitoring and maintenance at a low-level waste disposal site. If the net rate earned on the principal is larger than inflation, then the principal is left intact, and the principal can be invested again and again (in perpetuity) to fund these various activities through the return earned on the invested principal. However, if the interest rate earned on the principal is less than the inflation rate, or large extraordinary expenses develop that were not originally planned for, then the principal must be used if the activities are to be paid for. In that case, the principal is eventually reduced to zero, the perpetual care fund has a short life, and other resources besides those of the operator must be utilized.

9.4.3 Technical Requirements for Financial Assurances for Active Institutional Control

Based on a review of existing experiences with long-term care funds at commercial low-level waste sites, the staff has concluded that it is necessary to require licensees to establish financial responsibility for active institutional control and long-term care of a site. The staff has concluded that the licensee must provide financial assurances for active institutional control that includes all necessary expenses, including surveillance, monitoring, any necessary maintenance, and inflation. These costs are of a finite nature, because a "perpetual" care financial arrangement for low-level waste disposal sites is not required. Rather, financial responsibility for postclosure care during the 100-year active institutional contol period is required. To the extent that the licensee and the licensing authority have correctly estimated the types of activities necessary during this period, along with their resultant costs (adjusted for inflation), then the long-term care funding mechanism should be adequate to properly handle the known and predictable expenses of this 100-year period. However, it is beyond the scope of this long-term requirement to consider provisions for contingency costs. Beyond the period of 100 years, no expenses have been calculated for inclusion into the determination of long-term care responsiblity.

9.4.4 Types of Active Institutional Control Costs

A variety of studies have been performed that have analyzed types and estimates of costs for active institutional control at low-level waste sites. Appendix Q provides a discussion of these studies and cost estimates that were developed. For the 100-year active institutional control period, total costs at a reference disposal facility are estimated to range from between $8.5 million to $34.6 million (inflated dollars) depending on various site conditions.

9.4.5 Types of Active Institutional Control Funding Arrangements

A review of the various financial assurance mechanisms commonly used in the commercial law area (see Section 9.3.3) reveals that few if any of these mechanisms are suitable for the long-term nature of a long-term financial assurance mechanism. The extended time period (100 years) means that few financial institutions are willing or able to handle that type of long-term financial assurance. There are, however, several other alternative long-term financial assurance mechanisms that can be used for active institutional control at a disposal site. Several technical criteria were applied in reviewing the adequacy of alternative financial assurance mechanisms for long-term care. The staff considered that the most important consideration for long-term financial assurances was the extent to which they were able to provide a guarantee that the necessary funds would be produced by the responsible parties. Another necessary factor for consideration in evaluating the various financial assurance mechanisms at the federal government level was the extent to which enabling authority existed to allow the Commission staff to require such a mechanism. Several of the financial assurance mechanisms proposed by various parties would require enabling legislation that is currently lacking at the federal level. A brief description of these alternatives follows and each is described in greater detail in Appendix K.

9.4.6 Sinking Fund with Surcharge Recovered from Waste Generators

Several of the states currently require that their disposal licensees collect a specified surcharge from each waste generator who uses the site. The funds collected from these long-term care surcharges are then deposited into an earmarked state treasury account or sinking fund, where they are invested to keep pace with inflation. If such a sinking fund were used, in order for the regulatory agency to assure itself that there was protection to assure that funds for long-term care were available, a sinking fund would have to be combined with a performance bond on the unpaid balance. For example, suppose the regulatory agency determined that $10 million in 1980 dollars were necessary for active institutional control for 100 years. During the first year of operation the licensee might collect $.5 million from surcharges, which he would then deposit and then post a bond for $9.5 million. In the second year of operation, assuming that $1.0 million is deposited into the sinking fund, then the licensee would have to have a performance bond of $9.0 million, and so on. Such a fund could be set up in two ways. First, a fund could be established on a "perpetual" basis where the funds earned each year from the invested principal are used to pay for long-term activity costs. As long as the interest on the invested principal earned more than the inflation rate, and the net rate of return was positive, there would be sufficient funds for long-term care.

A second way that a long-term care fund could be set up is through the development of a finite period of control, such as a 100-year period. The funds would not be available in perpetuity, but rather for only a specified, finite period. The principal amount, which would be collected from surcharges on waste generators, would be drawn on over the 100-year period to pay for all necessary postclosure care, so that only a small amount of the principal and interest is left at the end of the 100-year period. Both of these two variants of long-term care funds are based on surcharges collected from waste generators. Although these two funding mechanisms have been used at the state level at commercial low-level waste disposal sites, the Nuclear Regulatory Commmission lacks the authority at the federal level to require that a surcharge (which is considered a tax) be imposed on waste generators. Therefore, the staff cannot recommend the use of this regulatory mechanism.

9.4.7 Low-Level Waste Disposal Site "Superfund"

Another type of financial assurance provision for active institutional control that has been proposed is the development of a federally administered long-term care program to which all disposal operators would be required to contribute. Using this scenario, the federal government would be responsible for administering a radioactive "Superfund," that is similar in nature to the fund being developed by the federal government based on P.L. 96-510. Proponents of this funding mechanism argue that, since burial sites serve national and not state needs, the citizens of individual states should not be required to bear the cost of major contingency actions for long-term care activities at these sites. The 1977 NRC Task Force Report on the Review of the Federal/State Programs for Regulation of Commercial Low-level Radioactive Waste Burial Grounds came to a similar conclusion. The report stated that "it appears desirable and equitable for the federal government to assume responsibility for long-term care of the sites, since the states generally do not have the resources to assure adequate care under a variety of contingencies and also since the sites serve regional needs." However, this type of pooled risk long-term care mechanism would require enabling legislation from Congress, since the authority to establish such a pool does not currently exist. Therefore, for the purposes of this regulation the staff cannot recommend the use of such a financial assurance mechanism.

9.4.8 Lease or Binding Arrangement

Another type of financial assurance mechanism suitable for active institutional control is the use of a legally binding arrangement such as a lease, between the licensee and the site landowner, wherein the two parties agree to assume varying degrees of responsibility between themselves for all required and predictable costs of long-term care of the site. Such a regulatory approach has been used since 1962, with mixed success at the commercial LLW disposal sites. The leases have generally specified that the licensee collect a surcharge of some amount from the waste generators. In several cases, the amount of the surcharge has been inadequate to generate sufficient funds for long-term care. The terms and conditions of the leases have also been subject to legal challenges by the licensees and the site owner.

9.4.9 No Financial Assurance Requirements for Active Institutional Control

Another long-term care alternative would be to not establish any funding requirement on waste licensees for financial responsibility. In such a scenario, the custodial care agency or the site owner would be responsible for all costs incurred during the active institutional control period. However, under this alternative, the waste generator would not be paying the full costs of the sites, resulting in an inequitable situation. Additionally, the staff did not consider a no action alternative for long-term care, since all of the existing LLW disposal sites have had some form of funding arrangement since the first site was licensed in 1962. The Commission staff has received numerous oral and written comments on the need to establish funding assurances for long-term care of low-level waste sites. The staff has determined that such a regulatory approach of not requiring a long-term care fund is not acceptable.

9.4.10 Acceptable Financial Assurance Mechanisms for Active Institutional Control

The staff has determined that all low-level waste disposal site operators must establish evidence of financial responsibility for long-term care of the site during the active institutional control period. Financial responsibility must be fixed well before closure for the costs of all required and necessary activities at the site, including surveillance, monitoring, inflation, and any required maintenance. Traditionally, states regulating existing commercial low-level waste disposal sites have required licensees to establish sinking funds based on surcharges collected from the waste generators, along with leases between themselves and the operator specifying financial responsibility for long-term care of the site. The staff is aware of the benefits of requiring disposal operators to require a surcharge on waste generators which is consequently deposited into a sinking fund and then invested. Such a cost recovery mechanism directly charges those parties benefiting (i.e., the waste generators) for the costs of long-term care. However, this approach cannot be used since the Commission lacks the authority to: (a) require that a long-term care fund be established, and (b) require that the operator impose a surcharge on waste generators. Appendix K of the EIS provides a description of the Commission's determination of these points.

Since the Commission lacks the authority to explicitly require that a surcharge be imposed and a sinking fund to be established, the staff considers that the next best regulatory alternative is to require that the operator be party to a binding arrangement such as a lease between himself and the site's landowner (current Commission regulations require the state or federal government to be the site land owner) which establishes evidence of financial responsibility for the 100-year institutional control period. The lease must also take into account changes in inflation over the 100-year period and the Commission will periodically review the lease to ensure that the terms and conditions are kept current by the parties to reflect changes in inflation, technology, and specific site conditions. More guidance on the specifics of this binding arrangement will be presented in a forthcoming regulatory guide to be issued by the Commission. The staff is aware of the shortcomings of such an approach, but considers this the best regulatory alternative based on the current statutory authority of the Commission. (States licensing disposal sites pursuant to the State Agreement Program may have enabling authority to require that a sinking fund be established, and that a surcharge be required of waste generators, and they may wish to consider such a regulatory alternative.) However, for the purposes of this regulation, the staff recommends that a low-level waste disposal applicant provide the Commission with an assurance that adequate financial resources will be available to provide for all known and predictable expenses that occur during the active institutional control period at the site following closure. Such a regulatory requirement will help to ensure that the licensee or the site owner is responsible for performing all required long-term care activities that are necessary to protect the public health and safety and the environment.

The staff has included the costs for 100 years of active institutional control into the cost of the reference facility, and corresponding alternatives that have also been analyzed. The actual costs of long-term care, however, will vary depending upon the level of active maintenance required under varying disposal facility conditions. The staff assumed that these funds for active institutional control would be obtained through a surcharge based on waste received at the facility. Monies obtained from the surcharge would then be placed into an interest bearing account.

Chapter 10

ENVIRONMENTAL CONSEQUENCES

10.1 INTRODUCTION

The purpose of this chapter is to identify, evaluate, and quantify the effects of the proposed rulemaking action: NRC's promulgation of a comprehensive regulation governing the management of low-level radioactive waste disposal (10 CFR Part 61). The environmental consequences or impacts discussed are based on the proposed rule as developed in previous chapters and do not include consideration of impacts of alternative versions of the rule. The consequences discussed are incremental, in some cases, with respect to the current regulatory framework.

Both direct and indirect environmental impacts will occur as a result of the proposed Part 61 rule. Direct impacts are discussed first in this chapter (Section 10.2) and, although such impacts are readily identified and evaluated, they are significantly different than the impacts typically considered in an EIS for a physical project such as a nuclear power plant or a fuel fabrication facility. Because this EIS is being prepared for a rulemaking action, the direct effects of the action do not fall upon the physical and natural environments, but rather upon those segments of the human environment whose conduct of affairs will be affected by the change in regulatory requirements. Among the directly affected groups considered in Section 10.2 are:

- Waste generators and processors;
- Waste transporters;
- Waste disposal facility operators;
- Federal agencies and the states; and
- The public.

Section 10.3 discusses the indirect impacts of the proposed Part 61 rule. In this section the performance objectives and minimum technical requirements of the rule are applied to four reference disposal facility sites located on a regional basis. Through this analysis, the residual or unmitigated impacts are identified which will occur even with the application of Part 61 requirements. By applying these requirements to a reference facility design and analyzing the benefits and residual impacts, the reader is provided with an estimate of the "real world" effects of the rule in terms that are more reflective of a typical project-specific EIS.

10.2 ENVIRONMENTAL CONSEQUENCES OCCURRING DIRECTLY AS A RESULT OF THE PROPOSED PART 61 RULE

10.2.1 Impacts on Federal Agencies

In Chapter 1 a number of federal agencies were identified which have responsibilities relative to low-level waste management. These agencies are: NRC, the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Department of Transportation (DOT) and the U.S. Geological Survey (USGS). The effects of the Part 61 rule on these agencies are discussed in the following subsections.

10.2.1.1 Impacts on NRC

In general terms, the chief impact of the adoption of 10 CFR Part 61 on NRC would be to more clearly define to the staff the established policies, licensing procedures, and performance objectives governing LLW disposal. It would also help ensure that LLW disposal facilities are treated uniformly in terms of complying with the above regulations and procedures.

Adoption of the Part 61 rule is not expected to significantly increase NRC's regulatory expenditures. Although the new requirements should result in some increased costs and effort, these probable increases in regulatory costs will be offset by gains in NRC's administrative efficiency. The application of a comprehensive set of regulations governing LLW will aid both potential licensees, the states, the public, and NRC by more clearly defining respective responsibilities, requirements, analyses, and determinations. In particular, NRC would have a uniform set of administrative procedures and performance requirements to apply in each instance. NRC would also have a set of clearly enunciated technical performance requirements that would permit more effective control of the performance and operating procedures of commercial LLW disposal facilities.

10.2.1.2 Impacts on EPA

The Environmental Protection Agency (EPA) is charged with the responsibility of protection and enhancement of environmental quality and it carries out its mission through research, monitoring, regulatory, and enforcement functions. An important EPA role with regard to low-level radioactive waste management is in the establishment of generally applicable environmental standards for waste disposal. The Agency does not license radioactive waste disposal facilities.

At the present time, the overall environmental standards for waste disposal are in the development process. The fact that EPA's standards in this field are not currently established required NRC to make a choice with regard to development of the Part 61 rule: proceed with rulemaking based on interim standards developed by NRC and coordinated with EPA, or suspend rulemaking until the EPA standards are formulated. NRC chose the former course of action.

In proceeding, NRC consulted with EPA on the performance objectives, minimum technical criteria, and other aspects of the rule. As a result of this coordinated effort, the technical criteria established in this statement and the rule itself will not impact the ongoing program of that agency for establishing overall environment standards for waste disposal. Rather, the NRC rulemaking effort may in fact advance EPA's efforts in this regard.

10.2.1.3 Impact on DOE

The Department of Energy (DOE) is responsible for managing disposal of low-level radioactive waste generated by government operations and for conducting research into various aspects of radioactive waste disposal. Disposal of LLW by DOE is exempted from NRC licensing authority and would remain so under the proposed Part 61 rule. Therefore, DOE's LLW disposal operations would be unaffected by the rule and could not come under its purview without an amendment to the Energy Reorganization Act of 1974.

One impact of the Part 61 rule on DOE would occur if DOE resumed using commercial disposal facilities for disposal of DOE LLW. Under this situation DOE would have to ensure that its waste conformed to applicable parts of the new rule. In addition, the Part 61 rule will help to provide additional specific guidance to DOE's programs of technology development and assistance to states in establishing new sites.

10.2.1.4 Impacts on DOT

Transportation of radioactive materials in the United States is jointly regulated by the Department of Transportation (DOT) and NRC. DOT regulates all radioactive materials in interstate commerce while NRC regulates the transportation of byproduct, source, and special nuclear material. The agencies continue to work closely in establishing standards and regulating packaging and other aspects of radioactive material transport. NRC's existing regulations for transport reflect the requirements of DOT and the situation will remain the same under the proposed Part 61 rule. The minimum requirements for waste form and packaging under the proposed rule are in compliance with existing DOT and NRC regulations and thus will not impact the regulatory program of DOT. The stability waste form requirements for higher activity wastes will help improve transportation safety as a byproduct, as will the minimum waste form requirements intended to improve operational safety at the disposal facility.

10.2.2 <u>Impacts on the States</u>

Promulgation by NRC of the proposed Part 61 regulation will have impacts on the states in addition to these realized by industry and federal agencies. These impacts will primarily affect those states which have entered into agreements with NRC for regulation of certain radioactive materials--i.e., the Agreement States.

Under provisions of the Atomic Energy Act, the states and NRC maintain compatible programs, which include specific rules and regulations. The promulgation of 10 CFR Part 61 would mean that the Agreement States would have to modify their regulations to include provisions compatible with the new NRC regulation. This process of modification would involve, at a minimum, the following steps:

- o Preparation of draft regulations to reflect the requirements of the Part 61 rule;

- o Review and approval of proposed regulations by NRC; and
- o Public review and formal incorporation into state code.

In preparation of this EIS, NRC has not attempted to quantify the actual costs which would be incurred by the Agreement States in modification of their programs. In part, this is because the periodic updating and modification of Agreement State rules and regulations to maintain a program compatible with NRC regulations is part of the normal functioning of the Agreement State program. Moreover, the Agreement State programs vary from state to state and the costs to one state to assure compatibility may not necessarily reflect the costs to another state.

10.2.3 Impacts on the Public

Promulgation of the proposed Part 61 rule by NRC will impact the public most significantly. The purpose of the rule is to provide improved safeguards for protection of public health and safety and the environment, but despite these improvements, the technology of waste disposal is not risk-free. Whatever risks remain in the presence of the operative rule will be borne by the public, as will the ultimate costs of implementing the rule. In the following paragraphs, the beneficial as well as the adverse impacts of implementing the Part 61 rule are considered.

10.2.3.1 Beneficial Impacts

The requirements of the Part 61 regulation are expected to result in beneficial impacts to the public in threee major areas. First, the implementation and enforcement of performance objectives and uniform minimum technical requirements will improve the performance of future LLW disposal facilities and thereby reduce the hazards of LLW disposal to public health and safety and environmental quality. Although the benefits of the rule's requirements may not be immediately apparent, the staff believes that in the long term these requirements will improve the stability of both the waste form and the disposal facility and will lessen the potential for radionuclide migration into the environment and the need for active long-term maintenance of the facility.

Second, the requirements of the Part 61 rule should assure that near-surface disposal remains a safe viable option for the disposal of LLW. Therefore, the public can be assured of the continued availability of goods and services whose provision results in generation of LLW. Among these goods and services are electricity from nuclear power plants, medical diagnostic aids based on nuclear technology, and research into new applications of nuclear technology.

Finally, the Part 61 rule provides public benefits in the form of more explicit provisions for participation in the licensing process for future LLW disposal facilities. Licensing requirements and procedures have heretofore been fragmented and somewhat difficult for interested citizens to fathom. As set out in the rule, these procedures are consolidated, and expanded provisions for participation by state and tribal governments are set out under Subpart F of the rule.

10.2.3.2 Adverse Impacts

The proposed Part 61 rule will result in benefits to the public. However, the staff does not expect that implementation of the rule will be without adverse public impacts. Three primary impacts are expected to occur.

The first of these impacts will be residual environmental and human health hazards resulting from LLW disposal. Despite the provisions of the Part 61 rule, the variables and processes involved in LLW disposal are sufficiently complex that unmitigated impacts cannot be avoided. These may include occupational exposure, migration of radionuclides, and subsequent offsite exposures. (Section 10.3 discusses these unmitigated impacts in more detail.) It should be noted, however, that these impacts are not impacts caused by the rule, but rather impacts which are considered beyond the capability of the rule to eliminate entirely.

Achieving reductions in impacts from LLW disposal will not be without costs in an economic sense. Implementing the requirements of the Part 61 rule will involve costs to the disposal facility operators, waste transporters, and waste generators. These costs, of course, will be passed on to the public in the form of increased prices for goods and services whose provision involves the generation of LLW. It is not expected that the passing on of these costs will create an incremental change to the consumer, but rather will appear along with many other costs of doing business in aggregate price increases.

Finally, implementation and enforcement of the provisions of the Part 61 rule will require the allocation of federal and state resources during the operational and postoperational periods of a LLW disposal facility. To the extent that these public resources are allocated to regulation of LLW disposal, they are unavailable for other purposes. Conversely, to the extent that the public incurs this cost, it reduces (within limits) the costs of LLW disposal in terms of human health hazards and environmental impacts.

10.3 ENVIRONMENTAL CONSEQUENCES OCCURRING INDIRECTLY AS A RESULT OF THE PROPOSED PART 61 RULE

This section discusses the indirect impacts of the proposed Part 61 regulation. To estimate these impacts, the performance objectives and minimal technical criteria established in Chapters 4 through 9 are applied to four reference disposal facilities assumed to be constructed on four hypothetical regional sites. Through this analysis, the residual or unmitigated impacts that could occur even with the application of the Part 61 requirements are addressed.

This section is divided into four subsections as follows. Section 10.3.1 provides a brief summary of the assumed regional sites, while a description of the disposal facilities assumed to be constructed at each regional site is provided in Section 10.3.2. The waste forms assumed for the regional case study analysis are also summarized in Section 10.3.2. Section 10.3.3 presents the results of the analysis in terms of radiological impacts and costs. Section 10.3.4 presents a discussion of other impact measures such as air quality, land use, and incremental energy use.

10.3.1 Hypothetical Regional Sites

This section presents a description of the four hypothetical regional sites assumed in this EIS. For the purposes of this EIS, the conterminous U.S. has been divided into four regions having boundaries based upon the existing five NRC regions. These are referred to in this EIS as the northeast region (NRC Region I), the southeast region (NRC Region II), the midwest region (NRC Region III), and the western region (a combination of NRC Regions IV and V). Each region is projected to generate from 600,000 to 1,000,000 m^3 of LLW between the years 1980 and 2000. A disposal facility is assumed to be located at a hypothetical site within each region. The western regional site description is meant to be representative of the southwestern portion of the region, and is usually termed the southwest site in this EIS.

Each site description has been developed from a number of sources and is meant to be consistent with: (a) the basic disposal facility siting considerations discussed in Chapter 5 and Appendix E, and (b) the generic environmental characteristics within that region. The regional site descriptions are intended to describe reasonable realistic sites--i.e., sites that could be licensed under the Part 61 rule--but are not intended to represent the "best" sites that could be located within the regions. Although the regional sites are meant to be typical of the environmental characteristics within the regions, the sites are not meant to describe any existing or potentially planned disposal facility or any specific location within a particular region. The site descriptions and ensuing case study analysis should also not be interpreted as NRC advocacy of any region or any specific location within a region. The principal purpose of the regional site descriptions is to provide a wide range of environmental conditions for consideration in the analysis.

The following provides a brief description of the regional disposal facility sites. More detailed descriptions are provided in Appendix E (southeast site) and Appendix J (the northeast, midwest, and southwest sites). A short summary of most of the principal site environmental properties used in the analyses is included as Table 10.1. Table 10.2 contains a summary of the (dimensionless) retardation coefficients assumed for the soils in the vicinity of the regional sites, while Table 10.3 contains a summary of the assumed population distributions.

10.3.1.1 Northeast Site

The northeast site is assumed to be located within the Appalachian Upland portion of the Appalachian Plateau physiographic province. The area has been reworked by erosional and depositional forces associated with glacial and postglacial activities. The disposal facility site is on an upland area, having an average elevation of about 555 m (1,820 ft) above mean sea level (msl). Throughout most of the Appalachian upland, the bedrock is overlain by unconsolidated deposits of glacial origin. The thickness of these units is generally greater in the lowlands and valleys, gradually thinning out over the upland. The material properties of the deposits are highly variable.

Table 10.1 Summary of Regional Disposal Facility Site Environmental Properties

Environmental property	Regional Sites NE	SE	MW	SW
Mean average temperature °C (°F)	8°C (46°F)	17°C (63°F)	11°C (51°F)	14°C (57°F)
Average wind speed km/hr	16.6	13	17	25
Average annual precipitation mm (in)	1,034 (41)	1,168 (46)	777 (30.5)	485 (19)
Average annual natural percolation (PERC) into groundwater system mm (in)	74 (2.9)	180 (7.1)	50 (2.0)	1 (.04)
Precipitation-evaporation (PE) index of site vicinity	136	91	93	21
Average silt context of site soils (%)	65	50	85	65
Average cation exchange capacity (meg/100g)	15	10	12	5
Groundwater travel time (yrs)				
Waste to:				
o Water table	50	10	23	277
o Site boundary	200	32	130	280
o Population well	2,500	400	2,100	580
o Surface water body	5,000	800	3,800	880
Distance (m)				
Waste to:				
o Water table	4	5	4	84
o Site boundary	30	30	30	30
o Population well	500	500	1,250	3,000
o Surface water body	1,000	1,000	2,500	6,000
Average transportation distance to regional facility (miles)	300	400	600	1,000

Table 10.2 Retardation Coefficients Assumed for Regional Disposal Facility Sites

Isotope	Regional Site NE	SE	MW	SW
H-3	1	1	1	1
C-14	10	10	10	10
Fe-55	5,400	2,640	2,640	1,290
Ni-59	3,600	1,750	1,790	860
Ni-63	3,600	1,750	1,750	860
Co-60	3,600	1,750	1,750	860
Sr-90	73	36	36	18
Nb-94	10,000	4,640	4,640	2,150
Tc-99	5	4	4	3
I-129	5	4	4	3
Cs-135	720	350	350	173
Cs-137	7,200	350	350	173
U-235	7,200	3,520	3,520	1,720
U-238	7,200	3,520	3,520	1,720
Np-237	2,500	1,200	1,200	600
Pu-238	7,200	3,520	3,520	1,720
Pu-239/240	7,200	3,520	3,520	1,720
Pu-241	7,200	3,520	3,520	1,720
Pu-242	7,200	3,520	3,520	1,720
Am-241	2,500	1,200	1,200	600
Am-243	2,500	1,200	1,200	600
Cm-243	2,500	1,200	1,200	600
Cm-244	2,500	1,200	1,200	600

Table 10.3 Population Distributions for the Regional Disposal Facility Sites

Distance From Facility	Northeast	Southeast	Midwest	Southwest
0-5 miles	3,400	2,000	3,100	60
5-10 miles	20,500	8,100	5,000	180
10-20 miles	73,600	36,000	27,900	3,500
20-30 miles	121,600	125,000	104,200	9,100
30-40 miles	556,600	203,400	121,900	4,900
40-50 miles	1,012,800	104,900	359,100	27,200

The site is underlain by approximately 9 to 23 m (30 to 75 ft) of compacted glacial till frequently referred to as hardpan or fragipan. Thin and discontinuous layers of sand and gravel are observed locally in the area. Coarser-grained sediments are principally found in valleys and lowlands, and are associated with stream channels. Underlying the glacial mantle are flat-lying rocks consisting of marine, black, and gray shales and siltstones, with some thin sandstone layers. The predominant soil types belong to the Brickton, Warren, Chitta and Highland series. The parent material consists of acidic, dense glacial till having a low lime content. The site has slopes ranging from nearly level to moderately rolling, and the runoff potentials are correspondingly variable. The soils are deep and generally poorly drained. Permeabilities for the uppermost foot of soils are moderate. However, the dense silty fragipan subsoil is of considerable thickness and is highly impervious.

Ground and Surface Water

Ground water generally occurs where the bedrock and glacial till meet. The depth to ground water at the site averages about 12 meters. The amount of ground water available in the local upland area where the site is located is largely limited to that which reaches the zone of saturation from precipitation falling upgradient of the site. This recharge quantity is small because of the low permeability of the till and the heavily vegetated nature of the land surface which acts to hold water in the surficial organic matter resulting in greater loss via evapotranspiration. Ground water occurrence in the bedrock is limited to secondary openings along fracture zones and bedding planes. Generally, the fine-grained character associated with the shales and siltstones inhibits water movement.

Ground water usage in this rural setting is very low, although the quality of ground water in the unconsolidated deposits and upper shale units is generally good. Pumpage is limited to widely scattered wells serving as domestic supplies to local homes and farmsteads. Most of these rural supplies are obtained from bedrock wells, 30 to 61 m (100 to 200 ft) in depth, and having average yields ranging between 23 to 38 liters per minute (6 to 10 gpm).

The site vicinity is generally sloping, with total vegetative cover. The surface soils and vegetation allow for considerable retention of precipitation; only 20 to 30 percent of precipitation becomes surface runoff. A strong correlation exists between stream discharge and precipitation in the site basin. Mean annual discharge at the outlet of the basin is about 1 m^3/s (35 cfs), but a wide variation in flow occurs throughout the year.

Meteorology

The climate in the area of the northeast site is classified as humid continental, characterized by wide variations in seasonal precipitation and temperature. Moisture sources for precipitation are obtained from the southerly flow of Gulf air during the summer, cyclones that originate in the Great Lakes, and Atlantic coast systems. Precipitation is uniformly distributed over the year with the greatest average monthly amounts occurring during April through September in the form of thundershowers. The average annual precipitation is approximately 1034 mm (41 in).

The area is characterized by distinct seasonal temperature variations. Winters are predominantly cold with maximum temperatures ranging from 0 to 20°C (32 to 36°F), and nighttime minimums of from -9 to -7°C (15 to 20°F). The temperatures are generally mild during June through August and maximum average temperatures range from 24 to 26°C (75 - 78°F).

The prevailing wind direction is southerly from May through November and westerly during the winter and early spring. The average wind speeds during these periods are 15.6 and 17.8 km/hr (8.4 and 9.6 knots), respectively. The average annual windspeed near the site is 16.6 km/hr (10.3 mph), and occurs from the west-southwest direction. Thunderstorms occur on an average of about 30 days per year and are more vigorous during the warm season. Tornados are not common but may occur between late May and late August. Freezing rain storms generally occur on one or more occasions during the winter but are of short duration.

Ecology

The site is located within the Appalachian Highland division of the Hemlock White Pine-Northern Hardwoods region. The region is characterized by a pronounced alternating presence of decidious, coniferous, and mixed forest communities. Approximately half of the county is currently used for agriculture, with much of the remaining area covered by secondary forest growth.

The disposal facility site itself is partially forested. The dominant species are sugar maple, American beech, yellow birch, hemlock, and white pine. The immediate vicinity of the facility is also forested to a great extent, continuous with the woodlands found onsite.

No state or federally declared rare or endangered species are known to occur onsite. A variety of mammalian species are found onsite, the most abundant being small mammals such as the white-footed mouse, short-tailed shrew, woodland jumping mice, and meadow vole. Common medium-sized mammals include woodchuck, oppossum, and gray squirrel. White-tailed deer are also abundant in this area. A moderate number of reptiles have been also observed or are expected to occur within the deciduous woodlands. The affected aquatic environment of the site is limited to Point Creek (2 mi from the site to the east) and its tributary, Boyle Creek (1 mi from the site to the south). Both Point and Boyle Creeks are considered Class C waters, best suited for recreational fishing. The major primary producers of these waters consist of several genera of diatoms, green and blue-green algae. The most common phytoplankton are Tubellaria, Fragillaria, Asterionella, and Cyclotella.

Land Use

The general region in which the site is located is comprised mostly of forested land and active or inactive farmland. There are no farm dwellings or other residences located onsite. The site is not suited for any unique uses, but soils are considered to have potential for farming. There is no significant mineral resource development within 10 km (6 mi) of the facility. County plans for the site, which is not in a visually sensitive area, and surrounding land (2 to 7 km) include forestation and compatible uses.

There are no known mineral resources of economical consequence within the vicinity of the northeast site. Recovery operations in the area are limited to a small bedrock quarry located one mile to the north, and a sand and gravel quarry located one mile to the east. No oil and gas reserves of economically recoverable quantities are known to exist in the site area.

10.3.1.2 Southeast Site

The southeast site is assumed to be located within the Liptone Upland segment of the Atlantic Coastal Plain physiographic province. For the purposes of this EIS, the southeast site description is assumed to be consistent with the reference facility site described in Appendix E and Chapter 3.

10.3.1.3 Midwest Site

Falling within the central physiographic province, the midwest site rests at an average elevation of about 247 m (810 ft) above mean sea level. The general topography of the site is that of a well dissected plain which is virtually encircled by various branches of the West Fork of Finley Creek. The regional topographic surface undergoes only small changes in relief.

Geology and Soils

A considerable thickness (approximately 35 m or 115 ft) of unconsolidated deposits underlies the site. Most of this is composed of a rather impermeable glacial till consisting predominantly of pebbly and sandy clay and silt, and gumbotil. (Gumbotil is a clay-rich till produced as a result of thorough chemical decomposition.) Portions of the glacial drift may contain sand and gravel pockets of limited areal extent.

The bedrock consists of approximately 30 m (100 ft) of Mississippian age rocks belonging to the Dette and Adams series. The uppermost formation of the Dette series, which generally acts as an aquiclude to the underlying Karesh and Becker formations, is absent from the site area. The Karesh limestone is thin and discontinuous over the Becker. Both formations are chiefly dense, crystalline, lithographic, or tightly cemented fragmental limestones and dolomites with very low porosities. The basal 3 m (10 ft) of the Becker consists of cherty sandstone. Underlying the Dette series are the dense, cherty dolomites and limestones of the Adams series. These two series make up what is known as the Mississippian Aquifer. They are underlain by approximately 400 feet of siltstones and shales of Devonian age that serve as a good aquiclude to the underlying Devonian Aquifer.

Soils

The entire area in which the site is located is covered by about 3 to 3.5 m (10 to 12 ft) of Wisconsin loess which is the parent material of the site soils. The predominant soil types are silty clay loams belonging to the Wancho, Houlik, and Lyle series. These soils are generally moderately slow to moderately well-drained and have permeabilities ranging between 5 and 50 mm/hr (0.2 to 2.0 in/hr).

Ground and Surface Water

Ground water of appreciable amounts occur chiefly in sand and gravel deposits associated with glacial drift and buried channel systems. These "drift aquifers" are notably limited in areal extent, though they sometimes serve as a source for farmsteads and livestock drinking water.

The depth to the seasonally high ground-water table under the site is expected to be about 12 m (38 ft) from the ground surface. Local ground-water movement in the drift aquifer will be governed by the topography, draining toward and being discharged into the various branches of the West Fork of Finley Creek. Ground water from the surficial aquifer, and also from the shallow bedrock aquifer, can be expected to discharge to the buried alluvial deposits.

Ground-water usage in the area is limited to consumption as needed by local homes and farmsteads for domestic, irrigation, and livestock supplies. It is estimated that the majority of wells tap Mississipian aquifers and to a lesser degree, the drift aquifers. Yields of less than 76 lpm (20 gpm) are the rule for this area.

The site is located in an locale that is undergoing dissection as a result of recent climatic change. Approximately 90% of the streams in the drainage area are intermittent, flowing only 6 to 8 months of the year.

Meteorology

The area has a humid continental climate, with a total annual local precipitation of 777 mm (30.5 in). Approximately two-thirds of the annual precipitation occurs during the months of April through September. The source of this precipitation is the warm moist southerly air from the Gulf of Mexico. The normal mean snowfall for the site area is approximately 686 mm (27 in).

The average annual temperature in the site vicinity is approximately 11°C (51.0°F). July is the hottest month, having an average daily maximum of 31°C (87°F) and an average daily minimum of 18°C (64°F). During January, the coldest month, the daily temperature range is approximately -0.6°C (31°F) to -11°C (12°F).

The prevailing wind direction at the site is southerly at an average speed of 17 km/hr (9.0 knots). During the months November through March, a northwesterly wind component develops in response to the Canadian cold air outbreaks. Wind speeds during these months average 22 km/hr (12.1 knots). Severe weather events such as thunderstorms and tornados occasionally occur during midspring to late summer.

Ecology

The natural vegetation within the vicinity of the site is a mixture of oak-hickory forest and bluestem prairie. The forest community occurs primarily along valley slopes and upland ridges. Big bluestem is the dominant grassland plant where the prairie remains. However, most of this area is cropland. The two major land uses in the county are pastureland (24 percent) and row crops (65 percent), with corn and soybeans representing the dominant crops. Almost 60 percent of the land area adjacent to the site is planted in corn.

No federally declared endangered or threatened species have been observed at or near the site. The most common mammals found onsite and within a five-mile radius are those for which corn is a predominant food source and can live in proximity to man. The most abundant species include the raccoon, striped skunk, eastern cottontail, opossum, and fox squirrel. Several burrowing mammals are also found in the area, primarily in fields not actively cultivated. Numerous resident bird species are also found onsite and in the surrounding cornfields. The most common species found, and which feed extensively on corn, include the redwing, cardinal, meadowlark, purple grackle, and common crow. Resident birds of prey include red-tailed hawk and great horned owl. Transient species include the coopers hawk, broad-winged hawk, and red-shouldered hawk. As a result of ongoing agricultural activities, the reptiles and amphibian population of the area is limited.

The West Fork of Finley Creek and its tributaries are Class B warm waters. Although the soils along the stream banks are moderately to highly erodable, the vegetated banks limit the amount of sediments that enter the streams. No federally declared endangered or threatened fish or snails are expected in these streams.

Land Use

The site is located on an area extensively used for cultivation of crops, mostly corn. Five houses are located within 5 km of the site. The site vicinity contains 4 towns--Mica, Grendle, Reed, and Lyme--but most of the land is not developed intensively. Hayer Industrial Park (10 acres) is located 4.8 km from the site. There are no other community facilities, historic places, or other visually sensitive land uses within an 8 km radius. Two state-owned lands, however, are located within 24 km of the site.

The chief source of economically important resources in the state lies in the substantial coal resources associated with Pennsylvanian age rocks. No such deposits occur under the site as the initial bedrock encountered is of Mississipian age. There is a potential for some natural gas deposits. However, the Ordivician source rocks are thin, making recovery unconsequential and uneconomical.

10.3.1.4 Southwest Site

The southwest site is assumed to be located within the Great Plains physiographic province. Regional topography shows sharply contrasting flat plains and rolling-to-rugged erosional breaks. The site has an estimated average elevation of 1219 m (4,000 ft) above mean sea level. As is characteristic of the area, the site is flat. Drainage is to the southeast and southwest to various intermittent branches of Hotsprings Creek.

Geology and Soils

Below a thin surface cover of loam and clay-loam soil are Pliocene age sedimentary deposits of the Bixler formation. These sediments were eroded from the ancient Rocky Mountains and transported by streams to this area. Because of their origin of deposition, their character varies both vertically and horizontally. As a general rule, however, the sand and gravels are in the basal portion of the formation.

The Bixler Formation is about 91 m (300 ft) thick in the site area. The upper 12 to 15 m (40 to 50 ft) is composed of caliche, a calcium-rich, carbonate-impermeable sandy clay similar to a hardpan. Underlying the caliche is approximately 15 m (50 ft) of dense, brown clay. Thin, discontinuous streaks of sand are also associated with the clays. The balance of the Bixler is composed principally of sand and gravel which extends down to the eroded surface of the Triassic rocks. The Triassic shales and sandstones belonging to the Maxwell group are estimated to be about 152 m (500 ft) thick in the site area. The first material encountered under the permeable Bixler strata is a red clay, indicative of the weathered shale surface.

The predominant soil types underlying the site are loams and clay loams belonging to the Starble, Nester, Wixman, and Jeeper series. These are moderately fine textured, calcareous, wind-blown sediments derived mostly from alluvial outwash from the Rocky Mountains. Because rainfall is low, there are long, dry periods, and soil development has been slow. The soils are seldom wet below the root zone, and, as a result, many of the soils have a horizon of powdery lime accumulation.

Ground and Surface Water

The Bixler formation is an unconfined aquifer with very limited consumptive use. The water occurs under water-table conditions, and differences in the thickness of the water-saturated material are closely related to the thickness of the Bixler formation. The saturated thickness underneath the site is only about 7.6 m (25 ft) as the water table lies some 84 m (275 ft) below ground surface.

The source of water (recharge) to the Bixler, and thence to the Triassic rocks, is precipitation on its more permeable surfaces. The amount of precipitation that enters the ground water is a very small percentage of the total precipitation falling at the surface. It has been estimated that less than 1 mm will reach the ground water annually. Due to the rather impervious nature of the onsite surficial materials, most of the precipitation will be lost by evaporation or drain to Hotsprings Creek as runoff. Part of this runoff will percolate downward through the coarser stream deposits and enter the ground water regime. This probably constitutes the major source of recharge within the area of the site. Some infiltration may work its way through the fractured portions of the caliche and slowly downward to the water table, but this is of limited quantity.

With the limited precipitation in the region, streams flow intermittently throughout the year. A wide variation in discharge occurs at the site. Since no base flow is known to occur in the area, precipitation accounts for all of the stream discharge. Short duration, high intensity thunderstorms account for the peak discharges from the site.

Meteorology

The climate of this site is considered semiarid, which is characterized by low humidity, wide temperature and precipitation variations, and frequent windstorms. The average annual precipitation for the site area is approximately 485 mm (19 inches). Departures from the norm can be great with extreme yearly totals ranging from 243 to 1010 mm (9.56 to 39.75 in). Nearly three-quarters of the total annual precipitation occurs during the months April through September, primarily in the form of thundershowers.

The average annual temperature for the site area is about 14°C (57°F). Maximum temperatures occur in the mid-summer months of June, July, and August. Rapid and wide variations are common, especially during the winter months when cold fronts from the Rocky Mountain and Plains States sweep across the plains. Temperature drops up to 16°C (60°F) occurring within a 12-hour period may be associated with these fronts. The highest recorded temperature in the region was 42°C (108°F) and the lowest was -27°C (-16°F).

The prevailing winds from March through October are southerly at 25 km/hr (13.6 knots), and southwesterly at 21 km (11.4 knots) during the winter months. The annual mean speed for all directional components is 24 km (13 knots) and southerly. These winds contribute to the evaporation rate associated with the region. The strongest winds generally occur in March and April and are associated with thunderstorm activity.

Ecology

The site area has been generally characterized as Grama Buffalo Grasslands. The most abundant native plant species are buffalograss, and blue grama. Total ground cover is relatively dense, and tends to increase under grazing. The preponderance of grass species results in large quantities of organic materials in the form of living and dead grass roots within the first ten to twelve centimeters of soil. Although various species of trees, including oaks, elms, and hackberries are often found along stream floodplains and steep-walled canyons, these are not found along Hotsprings Creek, an intermittent stream, or its intermittent feeder streams which surround the western, eastern, and southern portions of the site. Federally declared endangered species have not been observed within the site.

The mammalian fauna of this general area includes at least 50-60 species. During the hot daylight hours, a large number of mammals of this semiarid region live in burrows which they either dig themselves, or which they share or overtake from other species. The larger species which create their own underground burrows include the badger, plains pocket gopher, and swift fox.

Only the former two species were observed within 1 km of the site. Many other species also dig their own burrows, or use those of others, to escape the heat and predators, to search for food (insects, seeds, or other burrowing mammals) or to use as dens. However, these burrows are generally shallow.

Other nonburrowing mammals characteristic of this area and which have been noted onsite include the coyote, pronghorn antelope, bobcat, jackrabbit, great plains skunk, and eastern cottontail. The mixed grass prairie found onsite and in the general area also affords suitable habitat to numerous resident bird species. The most common small birds include Western meadowlark, dickcissel, bobolink, savanna sparrow, and prairie chicken. The most numerous resident birds of prey include the golden eagle, horned owl, and burrowing owl. Several species of lizards and snakes also inhabit the site. The more common ones include the northern earless lizard, prairie lizard, prairie rattlesnake, western diamondback rattlesnake, and bullsnake.

The aquatic environment of the site is limited to Hotsprings Creek and two feeder streams, all intermittent. After rainstorms when water does flow in the creeks and streams, aquatic biota is limited to algae, insects (which use the water to breed) and potential fish species such as minnows and sunfish. These fish survive the dry seasons by gathering in small pools of water that may remain throughout the year, and are then dispersed throughout the stream with the flowing waters.

Land Use

The site region is a plain containing numerous parcels of federally owned grassland. The site was privately owned before purchase by the state, and borders a federally owned parcel of the grasslands. There are no residences onsite or in the vicinity (1 mi) of the site. Portions of the immediately adjacent land (approximately 30%) extend onto the federally owned parcels, but most of it is privately owned.

The only known mineral resource occurring in the site area is caliche. This calcium carbonate cement is associated with sand and gravel deposits of the Bixler formation, and may be suitable for use as aggregate, however, these deposits are widespread throughout the entire region and do not represent unique resources.

Whereas numerous producing oil and gas wells have been drilled in the adjoining county, no historical production has occurred within the county in which the site is located. Prospect wells drilled within proximity to the site have not indicated the presence of oil or gas reserves of recoverable quantity.

10.3.2 Assumed Regional Disposal Facility Designs and Waste Source Term

This section provides a description of the disposal facilities assumed to be situated at the regional sites discussed in the preceding section, as well as the wastes which are assumed to be disposed in the facilities. The disposal facilities and waste forms described are intended to provide an example of potential impacts associated with disposal of waste according to the minimum requirements of the Part 61 regulation. These should not be interpreted as representing the best or the only designs or waste forms which could be implemented in compliance with the rule. There may be a number of ways in which the Part 61 requirements may be met for a specific disposal facility, and compliance with the Part 61 rule, as well as measures which may be implemented to reduce potential impacts to levels as low as reasonably achievable, would be evaluated on a case-by-case basis. The examples, rather, are intended to illustrate an upper bound range of impacts from implementation of the rule, with the expectation that actual impacts from implementation of the rule at existing or future disposal facilities would be less.

Assumed Facility Designs

The design assumptions for the four regional disposal facilities are summarized in Table 10.4. As shown, the assumed design cases all involve disposal in "regular" shallow land burial disposal cells. All disposal cells for the four regional sites are assumed to be constructed to 8 meter depths below the earth's surface. This introduces an additional conservatism regarding intruder and erosional impacts calculated for the southwest site, since the great depth to the water table at this site would allow construction to much greater depth than at the other three sites. All cases assume segregated disposal of waste streams containing organic chemicals as well as low activity unstable waste streams containing compressible material. Layering is used as an intruder barrier.

The principal differences among the four cases lies in the methods to limit contact of water with disposed waste and to minimize long-term maintenance requirements. For the three humid sites (northeast, southeast, and midwest), a moisture barrier in the form of a thick clay cap is installed and compacted using standard construction techniques. In the southwest site, there is assumed to be considerably less concern regarding ground-water migration due to the extreme depth of the water table and the semiarid climate. In this case, the standard "thin" cap is assumed to be installed. Similar to the humid sites, however, the disposed waste, backfill, and cap are assumed to be compacted using improved methods (e.g., a vibratory compactor). This helps to reduce voids within the disposal cell and therefore reduces the potential for settling and further reduces potential long-term maintenance costs.

Due to the relatively impervious nature of the soils at the northeast site, there is a greater chance for a water accumulation problem than at the other two humid sites. For this case, therefore, and to provide one case for analysis of a more extreme engineering design, increased attention (and expense) is assumed to be paid to stabilizing the disposal facility. This is represented by the assumption that all waste packages are stacked into disposal cells and grouted in place. In the other humid disposal facility sites, an imported sand backfill is assumed to be used to reduce the contact time of percolating water. Since the soils at these sites are more permeable than those at the northeast site, there is a lesser possibility of a water accumulation problem in the disposal cells containing unstable waste streams. At the southwest site, the originally excavated material from the site is used as backfill.

Table 10.4 Design Assumptions for Regional Disposal Facilities

Northeast

- o Regular SLB trench
- o Use of a thick clay cap
- o Compaction using improved methods
- o Segregation of wastes containing organic chemicals
- o Segregation of compressible wastes
- o Stacked disposal of waste
- o Grouting emplaced between waste packages
- o Layering used as an intruder barrier
- o Humid site having low permeable soils

Southeast

- o Regular SLB trench
- o Use of a thick clay cap
- o Compaction using improved methods
- o Segregation of wastes containing organic chemicals
- o Segregation of compressible wastes
- o Random disposal of waste
- o Use of a sand backfill
- o Layering used as an intruder barrier
- o Humid site having moderately permeable soils

Midwest

- o Regular SLB trench
- o Use of a thick clay cap
- o Compaction using improved methods
- o Segregation of wastes containing organic chemicals
- o Segregation of compressible wastes
- o Random disposal of waste
- o Use of a sand backfill
- o Layering used as an intruder barrier
- o Humid site having moderately permeable soils

Southwest

- o Regular SLB trench
- o Use of a "standard" cap
- o Compaction using improved methods
- o Segregation of wastes containing organic chemicals
- o Segregation of compressible wastes
- o Random disposal of waste
- o Backfill with originally excavated soils
- o Layering used as an intruder barrier
- o Semiarid site having highly permeable soils

All regional facilities are assumed to be operated for 20 years, followed by a two-year closure period and a five-year observation period prior to license termination and transfer of site control to the site owner.

Assumed Waste Forms

In the analysis, the higher activity waste streams are assumed to be stabilized. A number of techniques may be potentially used to achieve waste stability, ranging from solidification to improved waste packaging. To provide a range of costs and impacts for the calculation, therefore, two waste spectra are considered: waste spectra 2 and waste spectra 1 modified by use of high-integrity containers. In waste spectrum 2, all of the LWR process waste streams are assumed to be solidified. Half are solidified in cement and half in a synthetic polymer binder. Waste streams for which most of the activity is principally contained in activated metal (P-NCTRASH, B-NCTRASH, L-NFRCOMP, N-HIGHACT) are stabilized using improved packages (e.g., filling void spaces within the package with a noncompressible material, use of high integrity containers, etc.), as is the N-ISOPROD stream.

In modified waste spectrum 1, LWR process waste streams except for solidified concentrated liquids (P-CONCLIQ and B-CONCLIQ) are packaged in high-integrity containers. Concentrated liquids are still assumed to be solidified. High-integrity containers are also used for packaging two waste streams containing large quantities of tritium (N-TRITIUM and N-TARGETS). The other higher activity waste streams (P-NCTRASH, B-NCTRASH, L-NFRCOMP, N-HIGHACT, and N-ISOPROD) are again assumed to be stabilized through improved packaging techniques or high-integrity containers.

The two waste spectra--spectrum 2 and modified spectrum 1--are assumed to be applied in the analysis to all four regional disposal facilities without consideration of possible additional waste form requirements that could be implemented at a particular site. An example requirement would be the prohibition of certain types of organic chemicals at a particular humid site. In addition, at the northeast site there could be a requirement for use of stronger, more long-lasting waste containers for the unstable waste streams. These and other potential additional requirements were conservatively (in terms of ground-water impacts) ignored in the analysis.

In the analysis, the volumes of waste projected to generated in each region over a 20-year period are processed according to the waste spectra considered and delivered to the disposal facility. This results in a range in projected waste volumes (in m^3) for each region as follows:

Waste Spectrum	Northeast	Southeast	Midwest	Southwest
Modified spectrum 1	9.92E+5	1.07E+6	7.56E+5	7.26E+5
Spectrum 2	6.85E+5	7.51E+5	5.29E+5	4.91E+5

As shown, the largest volumes are projected for the southeast region.

10.3.3 Results of the Regional Analysis

This section presents a discussion of the indirect unmitigated impacts of implementation of the Part 61 rule based on analysis of the above regional cases. The section is divided into subsections as follows: 10.3.1, long-term radiological impacts; 10.3.2, short-term radiological impacts; 10.3.3, costs; and 10.3.4, other impacts (including nonquantifiable impacts such as impacts to biota and cultural resources).

10.3.3.1 Long-Term Radiological Impacts

Long-term radiological impacts for the regional case study are summarized on Tables 10.5 and 10.6. Potential individual and population intruder impacts are summarized on Table 10.5, as are potential erosional impacts. Groundwater impacts are summarized on Table 10.6. A range of impacts are shown in Tables 10.5 and 10.6, corresponding to the assumed use of either modified waste spectrum 1 or waste spectrum 2 to achieve stability of the higher activity waste streams.

Potential intruder and erosional impacts for the regional case study are summarized on Table 10.5. Individual intruder impacts are summarized for three organs (whole body, bone, and lung) for both the intruder-construction scenario and the intruder-agriculture scenario at time periods equal to 100 and 500 years following disposal facility closure. Population intruder impacts are also summarized as estimated at 100 years following facility closure. Airborne impacts are presented for whole body, bone, and lung as total populational exposures (in man-mrem) to persons living within 50 miles of the disposal facility. Waterborne impacts are presented for whole body, bone, lung, and thyroid to an individual who is assumed to use water from a surface stream contaminated from overland flow of material released from the facility by the intruder. Potential erosional impacts are also shown as impacts to populations for airborne releases and as impacts to an individual for waterborne releases. These are calculated at a time period equal to 2000 years following facility closure for the 3 humid sites and at 1000 years following facility closure for the southwest site.

As shown, the limiting individual inadvertent intruder impacts appear to be to the bone. In the analysis, the assumed use of grouting to stabilize the northeast site results in reduced exposures relative to the southeast and midwest sites. For these latter two sites, inadvertent intruder exposures averaged over the total waste volume disposed at the sites range from about 15 to 35 mrem at 100 years but drop to a few (4 to 9) mrem at 500 years. If the long-term reduction in intruder exposures brought about by the grouting is discounted for the northeast site, then potential exposures at 500 years would be expected to be similar to those for the southeast and midwest sites.

In the analysis, the increased volume reduction associated with waste spectrum 2 results in higher overall radionuclide concentrations then for modified spectrum 1, with resulting slightly higher estimated impacts. In the analysis, no credit has

Table 10.5 Summary of Potential Intruder and Erosional Impacts for Regional Case Study

Impact Measures		Modified Waste Spectrum 1				Waste Spectrum 2			
		Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Individual Intruder Impacts: (mrem)									
Body-100	C*	3.78E+0	2.29E+1	2.69E+1	1.71E+2	5.21E+0	2.93E+1	3.45E+1	2.32E+1
	A	1.97E+0	1.28E+1	1.59E+1	1.21E+1	2.80E+0	1.80E+1	2.24E+1	1.77E+1
500	C	2.02E-1	1.67E+0	1.85E+0	4.38E+0	2.53E-1	2.08E+0	2.30E+0	6.31E+0
	A	2.51E-1	1.89E+0	2.07E+0	3.43E+0	3.18E-1	2.34E+0	2.55E+0	4.87E+0
Bone-100	C	3.80E+0	2.32E+1	2.73E+1	2.09E+1	5.23E+0	2.97E+1	3.50E+1	2.86E+1
	A	2.51E+0	1.52E+1	2.02E+1	1.56E+1	3.47E+0	2.10E+1	2.75E+1	2.21E+1
500	C	3.92E-1	5.00E+0	6.19E+0	3.15E+1	5.29E-1	6.84E+0	8.50E+0	4.63E+1
	A	4.83E-1	3.66E+0	4.10E+0	7.20E+0	6.54E-1	4.87E+0	5.45E+0	1.04E+1
Lung-100	C	3.78E+0	2.30E+1	2.70E+1	1.83E+1	5.21E+0	2.94E+1	3.46E+1	2.51E+1
	A	1.81E+0	1.21E+1	1.46E+1	1.12E+1	2.61E+0	1.72E+1	2.09E+1	1.66E+1
500	C	2.84E-1	2.90E+0	3.64E+0	1.89E+1	3.73E-1	3.83E+0	4.86E+0	2.78E+1
	A	3.15E-1	2.36E+0	2.64E+0	4.49E+0	4.10E-1	3.01E+0	3.37E+0	6.43E+0
Population Intruder Impacts:									
Airborne (man-mrem)									
Body		6.45E+3	1.07E+3	1.77E+3	1.03E+1	5.61E+3	9.13E+3	1.55E+3	9.22E+0
Bone		1.70E+5	1.93E+4	3.22E+4	1.87E+2	1.02E+5	1.66E+4	2.80E+4	1.67E+2
Lung		5.30E+4	8.76E+3	1.46E+4	8.46E+1	4.61E+4	7.50E+3	1.27E+4	7.57E+1
Waterborne (mrem)									
Body		2.56E-3	1.07E-3	1.56E-3	1.16E-3	3.44E-3	1.41E-3	2.03E-3	1.55E-3
Bone		8.29E-3	3.17E-3	4.82E-3	4.36E-3	1.09E-2	4.04E-3	6.05E-3	5.78E-3
Lung		2.53E-4	1.38E-4	1.88E-4	1.33E-4	3.65E-4	1.97E-4	2.67E-4	1.96E-4
Thyroid		1.20E-4	5.92E-5	9.24E-5	6.85E-5	1.72E-4	8.41E-5	1.31E-4	1.01E-4

*See footnote, last page of table.

Table 10.5 (continued)

Impact Measures	Modified Waste Spectrum 1 Northeast	Southeast	Midwest	Southwest	Waste Spectrum 2 Northeast	Southeast	Midwest	Southwest
Erosion Impacts:								
Airborne (man-mrem)								
Body	1.59E+1	7.56E+0	5.84E+0	3.77E-1	1.59E+1	7.56E+0	5.84E+0	3.77E-1
Bone	3.11E+2	1.49E+2	1.42E+2	6.11E+0	3.11E+2	1.49E+2	1.42E+2	6.11E+0
Lung	2.91E+2	1.22E+2	1.03E+2	5.65E+0	2.91E+2	1.22E+2	1.03E+2	5.65E+0
Waterborne (mrem)								
Body	8.55E-2	9.43E-2	7.82E-2	2.92E-1	8.55E-2	9.43E-2	7.82E-2	2.92E-1
Bone	6.66E-1	7.67E-1	6.13E-1	1.68E+0	6.66E-1	7.67E-1	6.13E-1	1.68E+0
Lung	5.46E-1	5.32E-2	4.96E-2	1.44E-1	5.46E-2	5.32E-2	4.96E-2	1.44E-1
Thyroid	9.77E-1	1.18E+0	9.47E-1	5.90E-1	9.77E-1	1.18E+0	9.47E-1	5.90E-1

*Impacts are calculated at 100 and 500 years following disposal facility license termination. In the table, "C" stands for the intruder-construction scenario; "A" stands for the intruder-agriculture scenario.

Table 10.6 Summary of Potential Ground-Water Impacts for Regional Case Study

	(mrem/yr)							
	Modified Waste Spectrum 1				Waste Spectrum 2			
Impact Measures	Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Intruder Well								
Body	7.66E-1 (120)	1.35E-2 (6,000)	6.29E-2 (100)	1.41E-2 (100)	6.59E-1 (120)	7.74E-3 (100)	5.37E-2 (120)	1.39E-2 (100)
Bone	1.04E+0 (100)	3.17E-2 (6,000)	1.77E-1 (100)	4.46E-3 (100)	3.55E-1 (100)	2.70E-2 (6,000)	1.37E-1 (100)	3.60E-3 (100)
Thyroid	6.43E+0 (10,000)	5.62E+0 (6,000)	6.84E+0 (6,000)	2.53E-2 (100)	7.25E-1 (120)	6.36E-1 (6,000)	6.73E-1 (6,000)	1.45E-2 (100)
Boundary Well								
Body	1.16E-2 (10,000)	4.01E-2 (70)	1.15E-2 (10,000)	1.10E-4 (4,000)	3.97E-3 (8,000)	3.99E-2 (70)	2.66E-3 (10,000)	7.72E-5 (4,000)
Bone	1.98E-2 (8,000)	3.15E-2 (6,000)	6.84E+0 (10,000)	2.45E-2 (4,000)	1.65E-2 (8,000)	2.68E-2 (6,000)	9.01E-3 (10,000)	3.68E-4 (4,000)
Thyroid	6.02E+0 (10,000)	5.62E+0 (6,000)	6.84E+0 (6,000)	2.45E-2 (4,000)	6.52E-1 (8,000)	6.36E-1 (6,000)	6.73E-1 (8,000)	2.91E-3 (4,000)
Population Well								
Body	$<10^{-9}$ (10,000)	3.70E-3 (10,000)	4.55E-4 (10,000)	3.11E-6 (10,000)	$<10^{-9}$ (10,000)	1.42E-3 (10,000)	4.47E-5 (10,000)	1.89E-6 (8,000)
Bone	$<10^{-9}$ (10,000)	7.15E-3 (10,000)	1.90E-4 (10,000)	9.54E-6 (10,000)	$<10^{-9}$ (10,000)	5.84E-3 (10,000)	1.87E-5 (10,000)	8.75E-6 (8,000)
Thyroid	$<10^{-9}$ (10,000)	1.78E+0 (6,000)	3.26E-1 (10,000)	9.40E-4 (10,000)	$<10^{-9}$ (10,000)	2.01E-1 (10,000)	3.20E-2 (10,000)	1.11E-4 (8,000)
Surface Water								
Body	$<10^{-9}$ (10,000)	1.62E-4 (10,000)	$<10^{-9}$ (10,000)	*	$<10^{-9}$ (10,000)	5.89E-5 (10,000)	$<10^{-9}$ (10,000)	*
Bone	$<10^{-9}$ (10,000)	2.93E-4 (10,000)	$<10^{-9}$ (10,000)	*	$<10^{-9}$ (10,000)	2.36E-4 (10,000)	$<10^{-9}$ (10,000)	*
Thyroid	$<10^{-9}$ (10,000)	8.09E-2 (10,000)	$<10^{-9}$ (10,000)	*	$<10^{-9}$ (10,000)	9.14E-3 (10,000)	$<10^{-9}$ (10,000)	*

*Impacts at the surface water body are not calculated for the southwest site due to the intermittent nature of the nearest stream to the site and the extreme depth to ground water at the site.

been taken for improved waste forms to reduce dispersion and plant root uptake. This improved waste form would tend to reduce intruder exposures for waste spectrum 2.

As shown, the highest individual intruder exposures are estimated to occur at the southwest site. These exposures run at about 46 mrem to bone but are still a factor of 10 less than the 500 mrem limit. The increased exposure is due to the increased silt content of the site soils as well as the increased wind speeds relative to the other three sites. These impacts are believed to be very conservative, since the great depth to the water table allows disposal at much greater depths than at the other three sites--further reducing the potential for inadvertent intrusion into the more highly active waste streams.

With respect to the southwest site, the opposite trend is seen for the intruder airborne population impacts. These run at a few orders of magnitude less than for the other two sites and are principally due to the low population density in the environs of the site. On the other hand, the waterborne impacts all appear to be comparable for the four facilities and are all very low--i.e., on the order of 10^{-3} mrem or less.

The intruder population airborne and waterborne impacts may be compared to those for the assumed erosion event. (It may be repeated that disposal facilities under the Part 61 regulation would be sited to avoid problems with erosion, and the estimates are, therefore, a rather improbable upper bound of potential impacts.) The airborne impacts are again reasonably comparable for the three humid sites and (due to the lower expected population density) a few orders of magnitude less for the southwest site. Waterborne impacts are also more or less comparable, with the highest impacts at 1.7 mrem (to bone) and occurring at the southwest site. This is still less than the ground-water migration limit of 4 mrem at the nearest drinking water supply.

As shown in Table 10.6, the highest exposures due to ground-water migration are to the thyroid, although in all cases the performance objectives as set out in Chapters 4 and 5 for inadvertent intrusion and ground-water migration are met. The estimated impacts reflect the differing volumes of waste streams and corresponding radionuclide inventories within each regional facility, as well as the differing environmental characteristics of each regional site. Of the three humid regional disposal facilities considered (northeast, southeast, and midwest), reasonably comparable impacts are estimated at the intruder well and the boundary well. For the intruder well, the highest exposures to whole body and bone (.8 mrem and 1 mrem, respectively) occur at the northeast site. Intruder well exposures to thyroid are very similar among the three humid sites, with the highest exposures (7 mrem) occurring at the midwest site, followed by the northeast site. For the boundary well, the highest exposures to whole body and bone (.04 mrem and .03 mrem, respectively) are estimated for the southeast site, while the highest thyroid exposures (7 mrem) are again estimated for the midwest site.

Of the three humid regional sites, the southeast is assumed to experience the largest percolation component (PERC) as well as the quickest ground-water travel times to biota access locations. In addition, the midwest and southeast site soils are assumed to have moderate retardation capabilities (NRET=3) while the retardation capability of the northeast site soil is higher (NRET=4). The influence of these factors is clearly seen in calculated exposures for the population well and the surface water body. The highest estimated population well and surface water body exposures occur at the southeast site. Population well thyroid exposures for the midwest site are about 5 times less than those for the southeast site. Surface water exposures for the midwest site are all less than 10^{-9} mrem at 10,000 years following disposal facility closure.

The southwest site is somewhat of a different case. The site is assumed to be located in a semiarid area and a water balance calculation for the site indicated that due to the low rainfall and high evapotranspiration, essentially no precipitation falling upon the site reaches the underlying aquifer. For completeness in this analysis, however, a percolation coefficient of 1 mm was conservatively assumed for the site. The resulting estimated exposures are a few orders of magnitude less than those for the other three sites at the intruder, boundary, and population wells. The surface water body exposures are not presented for the southwest site, however. The closest water body down-gradient of the site is an intermittent stream, and in any case, the water table is located on the order of 80 meters below ground surface.

10.3.3.2 Short-Term Radiological Impacts

Short-term radiological impacts for modified waste spectrum 1 and waste spectrum 2 are summarized in Table 10.7. Included in this table are (1) potential impacts to populations (in man-mrem) from transporting waste to the regional facilities, (2) potential occupational impacts (in man-mrem) associated with processing, transporting, and disposing of waste within the region, and (3) potential impacts from an operational accident at the disposal facility averaged across all wastes transported to the facility.

As shown, transportation impacts over 20 years range from about 420 to 1,100 man-rems, or about 21 to 55 man-rems per year. Of interest is the narrow range of impacts for the three humid sites compared to the higher (about double) impacts calculated for the southwest. The higher estimated impacts are due to the greater transportation distance for the western region as compared to the other three regions (1,000 miles vs. 300 to 600 miles).

Occupational impacts are listed as total impacts over 20 years for waste processing, transportation to the disposal facility, and waste disposal. Waste processing occupational exposures are presented as additional exposures to those associated with waste spectrum 1.

Also included are the occupational exposures that are estimated to be associated with operation of a regional processing center. For waste spectrum 2, waste processing is assumed to consist of compaction of compressible waste streams by large compactor/shredders. This is likely not be a cost effective operation but has been included for completeness. It may also be of interest for the sake of completeness to list occupational exposures and other impact measures estimated to be associated with incineration of the same waste streams at the regional processing centers. These impact measures--population exposures due to airborne releases from the incinerators, occupational exposures from operation of the regional processing center, and costs--are listed in Table 10.8. All impacts are over 20 years of facility operation.

Table 10.7 Summary of Short-Term Radiological Impacts for the Regional Case Study

Impact Measures	Modified Waste Spectrum 1				Waste Spectrum 2			
	Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Transportation Population Impacts: (man-mrem)	4.16E+5	6.02E+5	6.54E+5	1.10E+6	4.02E+5	5.97E+5	6.52E+5	1.08E+6
Occupational Impacts: (man-mrem)								
Waste Process								
By Generators	-	-	-	-	+1.70E+6	+1.98E+6	+1.50E+6	+9.00E+5
Regional Center	0	0	0	0	1.81E+5	7.15E+4	1.08E+5	9.02E+4
Transportation	5.54E+6	6.92E+6	5.04E+6	4.89E+6	5.21E+6	6.43E+6	4.79E+6	4.54E+6
Waste Disposal	5.10E+6	2.96E+6	2.03E+6	2.80E+6	4.78E+6	2.81E+6	1.96E+6	1.68E+6
Accident at Disposal Facility: (mrem)								
Dropped container								
Body	1.36E+0	1.98E+0	1.66E+0	5.93E-1	1.33E-1	1.27E-1	1.17E-1	7.10E-2
Bone	3.00E+0	4.44E+0	3.65E+0	1.32E+0	3.47E-1	4.45E-1	3.91E-1	2.44E-1
Lung	1.25E+1	1.88E+1	1.57E+1	5.59E+0	7.12E-1	9.51E-1	8.03E-1	5.36E-1
Fire in disposal cell								
Body	4.70E+0	3.19E+0	3.97E+0	3.63E+0	7.09E+0	4.87E+0	5.92E+0	5.72E+0
Bone	1.15E+1	1.20E+1	1.38E+1	1.27E+1	1.73E+1	1.83E+1	2.07E+1	2.00E+1
Lung	1.73E+1	1.97E+1	1.93E+1	1.86E+1	2.60E+1	3.00E+1	2.89E+1	2.93E+1

Table 10.8 Summary of Population Exposures, Occupational Exposures, and Costs for Regional Incineration

Impact Measures	Northeast	Southeast	Midwest	Southwest
Population exposures: (man-mrem)	4.19E+4	2.95E+4	3.70E+4	2.71E+4
Occupational exposures: (man-mrem)	3.67E+4	1.34E+4	2.08E+4	1.77E+4
Costs: ($)	1.39E+8	5.41E+7	8.22E+7	6.88E+7

As expected, the largest occupational exposures for waste disposal are those estimated for the northeast site. This is due to the assumed additional operational practices carried out at the northeast site.

Operational accidents are listed for the two potential scenarios considered in this EIS--a waste container accidentally dropped from a height and an accidental fire in a disposal cell. Impacts are calculated in an extremely conservative manner and are to an individual potentially standing approximately 100 m immediately downwind of the accident. In addition, impacts are averaged over all waste streams delivered to the disposal facility.

10.3.3.3 Costs

Costs, including waste processing, transport, and disposal costs are listed in Table 10.9. Similarly to occupational exposures, costs due to processing the waste by the waste generator are presented as additional costs to those associated with waste spectrum 1. For the modified spectrum 1 case, these additional costs involve stabilizing high activity waste streams at an estimated cost of \$450 per m^3 of waste so stabilized, which is the approximate cost of placing the waste streams into high-integrity containers. It is expected that some of the waste streams may be stabilized by less expensive means; however, using the high integrity container costs provides an upper bound. For waste spectrum 2, stability of many of the waste streams--particularly LWR process waste streams--is provided through solidification. Costs for stabilization of other waste streams is again represented by estimated costs for high integrity containers. Finally, in waste spectrum 2, additional costs are incurred through compaction of compressible waste streams, both by waste generators and at a regional center.

Of these costs, the only additional waste processing costs that would be incurred through implementation of the Part 61 regulation would be through stabilization of the higher activity streams. For waste spectrum 2, these are conservatively estimated as follows:

Table 10.9 Summary of Costs for Regional Case Study

	(mrem/yr)							
	Modified Waste Spectrum 1				Waste Spectrum 2			
Impact Measures	Northeast	Southeast	Midwest	Southwest	Northeast	Southeast	Midwest	Southwest
Waste Processing Costs: ($)								
Waste Generator	+7.28E+7	+9.89E+7	+6.63E+7	+5.22E+7	+3.47E+8	+3.95E+8	+2.92E+8	+1.91E+8
Regional Center	0	0	0	0	+5.29E+7	+2.07E+7	+3.14E+7	+2.63E+7
Waste Transportation Costs: ($)	1.45E+8	2.43E+8	2.40E+8	3.41E+8	1.32E+8	2.18E+8	2.22E+8	3.08E+8
Waste Disposal Costs: ($)								
Design & Op.	2.75E+8	2.10E+8	2.01E+8	1.89E+8	2.53E+8	2.01E+8	1.94E+8	1.86E+8
Post operational	1.26E+7	1.91E+7	1.91E+7	1.26E+7	1.26E+7	1.26E+7	1.26E+7	1.26E+7
Total	2.88E+8	2.29E+8	2.20E+8	2.02E+8	2.66E+8	2.14E+8	2.07E+8	1.99E+8
Unit ($/m^3)	290	214	291	278	388	285	391	405

Waste Spectrum 2	Northeast	Southeast	Midwest	Southwest
$(x10^8)	2.82	3.58	2.70	1.64
$/m^3	1363	1310	1390	1158

Thus, the requirement that higher activity wastes be stabilized would appear to involve additional processing costs in the following range.

	Northeast	Southeast	Midwest	Southwest
Low ($x10^7)	7.3	9.9	6.6	5.2
High ($x10^7)	28.2	35.8	27.0	16.4

This range is believed to be conservatively high, however. In addition, much of the above costs would be expended in any case to comply with license conditions already implemented by the states at existing disposal facilities.

Waste transportation costs range from about $130 to $240 million, depending upon the waste spectra and the region considered. The largest costs are for the southwest region, for which the reduced volume of waste relative to the other three regions is counterbalanced by the longer transportation distances. The effects of the Part 61 regulation on transportation costs is expected to be low. Use of high-integrity containers to stabilize higher activity waste streams would result in little or no increased waste volume and would therefore not increase transportation costs. On the other hand, use of solidification to stabilize higher activity waste streams such as ion exchange resins would tend to increase waste volumes and thus increase transportation cost. However, if solidification is coupled with volume reduction of compressible waste streams through compaction (which improves disposal facility stability), then, as shown for waste spectrum 2, overall transportation costs could be reduced.

Waste disposal costs are set out into design and operational costs and post-operational costs, where postoperational costs include costs to waste customers (over 20 years of operation) for providing for: (1) facility closure, (2) a 5-year observation and maintenance period, and (3) 100 years of institutional control. Also shown are total disposal costs as well as unit ($/m³) costs.

As shown, the most significant design and operational costs are for the northeast site, due to the assumed use of grouting to assure stabilization of wastes. The design and operational costs for the other three sites are clustered within a relatively small range. In addition it may be observed that reducing the waste volumes delivered to the site also lowers the design and operational costs, although not proportionately. Due to the use of the grouting at the northeast site, a low level of postoperational costs are projected for this site. The southwest site is also projected to experience a low level of postoperational costs, due to the semiarid nature of the site. A low to moderate range in postoperational costs, however, is projected for the southeast and midwest sites. A low level of postoperational costs is projected for waste spectrum 2 due to the assumed extensive compaction of compressible waste streams. Since this extensive compaction is not carried out for modified waste spectrum 1, a somewhat higher potential for maintenance is assumed and a moderate level of postoperational costs is conservatively projected.

Unit costs are seen to vary widely depending upon the assumed design and operating practices carried out at the particular disposal facility as well as the volumes of waste delivered to the facility. For example, the design and operation of the southeast site is essentially the same as the midwest facility. However, the volume of waste delivered to the midwest facility is much less than the southeast facility, while the design and operational costs are only slightly less. This is because capital costs to construct the disposal facility are much less dependent upon the volumes of waste delivered to the facility than the operating costs. Many of the same expenses to design, build, and operate the facility would be incurred whether a high or a low volume of waste was received.

10.3.3.4 Other Impacts

This section discusses indirect impacts associated with the proposed Part 61 regulation other than radiological impacts or costs. The impacts are broken down into the following subsections: Air quality (nonradiological), biota (ecology), land use, energy use, and social impacts.

Air Quality

Nonradiological impacts to air quality due to LLW management and disposal would principally arise from two sources: combustion of fossil fuels during processing, transporting, and disposing of waste and (2) particulate matter (dust) released into the air due to earth moving activities at the disposal facility. Typical combustion products would include suspended particulates, sulphur dioxide, CO_2, CO, various hydrocarbons, and various nitrogen oxides.

It is believed that implementation of the Part 61 regulation would have a relatively slight effect upon overall air quality. For example, increased waste processing such as compaction and solidification would probably result in increased combustion of fossil fuels, with correspondingly increased release of combustion products into the air. However, many waste generators are already performing such waste processing activities to reduce transportation costs or to comply with existing license conditions at disposal facilities. Moreover, waste processing activities that reduce waste volumes would tend to reduce releases of fossil fuel combustion products during transportation.

At the disposal facility, local impacts to air quality result from combustion of fossil fuels by vehicles delivering waste to the facility, by vehicles owned by facility personnel, and by heavy equipment operated at the facility. Dust could be raised by excavating, backfilling, and grading activities. However, combustion of fossil fuels and earth-moving activities are not unique to the fact that it is a disposal facility. Similar types of impacts can and would be raised by many other types of small industrial concerns.

Since the Part 61 regulation emphasizes increased disposal facility stability, somewhat additional air quality impacts could result during the operating life of the disposal facility. That is, additional personnel may be needed as well as additional equipment to segregate waste, carry out improved compaction techniques, install improved disposal cell covers, and so forth. However, such additional impacts would be felt only during the time the facility was operating. In addition, if the facility was left in an unstable condition after operation, increased longer-term air quality impacts could result due to operating machinery to repair holes in disposal cell covers, potential operation of a leachate evaporator, and so forth. Placing the facility in a more stable condition during site operations reduces the maintenance that would be required after closure and during the institutional control period. Since less maintenance would be required, lower longer term nonradiological air quality impacts would result.

Biota

The operation of a disposal facility would involve acquiring and fencing in up to a few hundred acres of land. Existing vegetation would be mostly cleared, and after waste disposal, the disposal cells would be regraded, recontoured, and probably reseeded with short-rooted local vegetation. During this process, impacts to biota could result from destruction of habitat. Such impacts would again not be caused by the fact that the facility is used for waste disposal, but arise from the decision to change the land from one use to another. Similar types of impacts would result from other uses of the land which involve heavy construction. These could include, for example, clearing the land for a small industrial concern, a school, a farm, and so forth.

Implementation of the Part 61 rule is expected to have little effect on the potential for impacts to biota. There are already existing federal and state laws and regulations governing protection of endangered or unique flora and fauna. These regulations and laws would be considered during licensing of a disposal facility whether or not the Part 61 regulation is implemented. To the extent that the Part 61 regulation makes the requirement of considering endangered or unique flora and fauna more explicit during licensing, however, overall impacts to biota could potentially be reduced.

Land Use

In most cases, the operation of a licensed nuclear facility by a licensee does not result in the land being permanently committed to that activity. That is, at the end of operation of the facility it may be decontaminated, if necessary, and used for another purpose. At an LLW disposal facility, however, possible future use of the facility after it has closed is greatly influenced and somewhat circumscribed by the presence of the disposed waste. This does not mean that land used for LLW disposal is permanently excluded from productive use. Rather, as long as care was taken to restrict activities to those which would not involve excavating into the disposed waste or bringing contamination to the surface, there may be a number of useful purposes the facility surface may be put to. These could possibly include use of the facility for grazing, golf courses, recreational areas, or light industry.

Notwithstanding this, however, it is useful to consider the amount of land that would be committed to LLW disposal over the next 20 years. It is difficult to assess the influence of the Part 61 regulation on this land use. Depending upon the design and operation of the disposal facility and the manner in which higher activity wastes are stabilized, land use could be lower or potentially higher than without the regulation. A range in land use may be estimated, however, using the regional analysis as a guide. Land use for each of the regions is shown below for the 2 waste spectra considered in the analysis.

	$m^2 \times 10^5$ (acres)			
	Northeast	Southeast	Midwest	Southwest
Modified Waste Spectrum 1	2.30 (56.8)	3.72 (91.9)	2.62 (64.7)	2.52 (62.3)
Waste Spectrum 2	1.59 (39.3)	2.61 (64.5)	1.84 (45.5)	1.71 (42.3)

As shown, land use ranges from about 160,000 m^2 to 370,000 m^2 at the regional sites, depending upon the volume of waste disposed and the disposal technology implemented. For modified spectrum 1, the total amount of land committed to LLW disposal over 20 years is estimated to be 1.1 million m^2, or about 276 acres. For waste spectrum 2, for which increased use is made of volume reduction, this land use is reduced to 775,000 m^2 or 192 acres. This includes an assumed 3-meter spacing between disposal cells but does not include other land such as administrative areas, buffer zones, onsite roads, and so forth.

Energy Use

One way in which the effects of a proposed action can be quantified is to estimate the total energy requirements associated with that action. In terms of LLW management and disposal, this would be a difficult project given the large number of waste generators, the many different types and forms of LLW, and the many possible processing techniques that could be used. As a simplification, then, an effort has been made to estimate the increase in energy use due to the promulgation of the Part 61 rule. This is still realized as a difficult task given the recent increase in the level of waste processing activities carried out by waste generators. In addition, there may be a number of ways in which the Part 61 requirements may be met and there are considerable uncertainties regarding the energy use associated with various technologies, etc.

In any case, bounding estimates can be made using the regional analysis as a guide. The estimated increase in energy use due to the Part 61 regulation is listed below in gallons of equivalent fuel for each region for both waste spectra considered:

	(gal x 10^5)			
	Northeast	Southeast	Midwest	Southwest
Modified Waste Spectrum 1	+0.6	-2.7	-2.6	-1.86
Waste Spectrum 2	+83.1	+89.7	+64.7	+21.3

As shown, incremental energy use ranges from -270,000 gal to +8,970,000 gal. It should be realized that there are large uncertainties in these calculations. Much of the projected increase in energy use is due to activities such as increased disposal stability or increased waste processing which by and large are already being carried out. In general, the overall tendency of the Part 61 regulation would be to increase short-term energy use but reduce long-term energy use.

Social Impacts

In general, social impacts due to promulgation of the Part 61 regulation are difficult to address. These impacts are very site-specific and would include such aspects as the effect of bringing a labor force into an area on local utilities, schools, and other services. These types of impacts are typically of most concern during the siting, construction, and operation of large facilities such as a large nuclear power plant. A low-level waste disposal facility is by comparison a very small operation, and the proposed Part 61 regulation is not expected to result in any significant incremental changes in social impacts associated with operation of LLW disposal facilities.

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*: NUREG-0782, Vol. 2

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Draft Environmental Impact Statement on 10 CFR Part 61: "Licensing Requirements for Land Disposal of Radioactive Waste", Main Report

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
NRC Staff

5. DATE REPORT COMPLETED
MONTH: Sept. YEAR: 1981

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, DC 20555

DATE REPORT ISSUED
MONTH: Sept. YEAR: 1981

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Same as 9.

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.

13. TYPE OF REPORT
Draft Environmental Impact Statement

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*
The four volume draft environmental impact statement (DEIS) is prepared to guide and support publication of a proposed new regulation, 10 CFR Part 61, for the land disposal of low-level radioactive waste. The analysis in the DEIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design of disposal facilities, the method of operation of the facilities, institutional controls, financial assurances, and administrative and procedural requirements. From the analysis, four main performance objectives are established in the proposed regulation relating to (1) minimizing long-term social commitment and costs, (2) minimizing long-term environmental releases, (3) minimizing long-term impacts to humans potentially inadvertently intruding into disposed waste, and (4) assuring short-term operational safety. Based upon the analysis and overall performance objectives, a number of technical, financial, procedural, and administrative requirements are also developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
groundwater migration
inadvertent intrusion
10 CFR Part 61
waste form
financial assurances
institutional controls
radioactive waste
disposal technologies
cost-benefit analysis

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*: Unclassified

20. SECURITY CLASS *(This page)*: Unclassified

21. NO. OF PAGES: 429

22. PRICE: $

Newman

NUREG-0782
Vol. 3

Draft
Environmental Impact Statement
on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices A-F

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street., N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, transactions, and codes and standards. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

NUREG-0782
Vol. 3

Draft Environmental Impact Statement
on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices A-F

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

VOLUME III

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Appendix D   Low-Level Waste Sources and Processing Options

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Appendix E (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

List of Tables

List of Tables (Continued)

List of Tables (Continued)

Appendix A

(Reserved for Staff Analysis-Public Comments on Draft EIS and Proposed Part 61 Rule)

Appendix B

(Reserved for Public Comments on Draft EIS and Proposed Part 61 Rule)

Appendix C

PUBLIC PARTICIPATION IN THE DEVELOPMENT OF THE LLW DISPOSAL REGULATION

1. SUMMARY

This section provides an overview of the means that NRC has used to provide public participation in the development of the low-level radioactive waste (LLW) disposal regulation.

A broad, flexible program for the orderly development of comprehensive regulations governing the management and disposal of LLW by shallow land burial or other alternative methods was initiated and subsequently announced in the Federal Register on December 7, 1977 (42 FR 61904). This program is currently in progress.

The staff initiated a study to provide a broad analytic base for a waste disposal classification system providing a foundation for the forthcoming regulations and accompanying environmental impact statement (EIS). A document (NUREG-0456) describing the classification system and applications was published in June 1978. A Federal Register notice (43 FR 36722) was issued on August 18, 1978 to announce the availability of the document and to request public comments on the in-progress study. Comments received by the NRC have been used to guide the further development of the methodology and its application to rulemaking.

In an October 25, 1978 Federal Register Advance Notice of Proposed Rulemaking (43 FR 49811), the Commission requested advice, recommendations, and comments on the scope and content of an environmental impact statement to guide and support the development of a regulation, 10 CFR Part 61, for the management and disposal of low-level waste.

The comments received by NRC on the Advance Notice were utilized by NRC staff in scoping the form and content of an EIS and LLW disposal regulation. To help focus development on the draft EIS and proposed LLW disposal regulation, NRC staff prepared a preliminary draft regulation 10 CFR Part 61 (draft dated November 5, 1979). The November 5th preliminary draft regulation received wide distribution and copies were sent to state liaison officers, federal and state agencies, industry, public interest groups, and others. In addition a Federal Register notice (45 FR 13104) was issued on February 28, 1980 to announce the availability of the November 5, 1979 draft document and to request public comments. Comments received have been used during further development of the regulation and preparation of the EIS.

During 1980, the NRC held four regional workshops in Atlanta, Chicago, Denver, and Boston, that provided state officials, industry representatives, waste generators, the public, and private interest groups with an opportunity to comment on the preliminary draft regulation and other issues that need to be addressed and resolved. The comments received at these workshops have been used during further development of the regulation.

In summary, the NRC has continuously sought and obtained a broad range of input from the states, public and industry on the approach, issues and considerations to be addressed in upgrading regulations concerning the management and disposal of LLW. Copies of all comments, transcripts and reports constituting this input have been placed in the Public Document Room of the NRC as part of the record of this rulemaking procedure. This input has been used during the development of 10 CFR Part 61.

2. BACKGROUND

The NRC has been continuously involved in the reexamination of the technical and regulatory bases for low-level waste management. In mid-1976, an NRC Task Force was created to review programs used by the NRC and state governments to regulate disposal of commercial low-level waste. A document entitled, "NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds" (NUREG-0217) was published in March 1977. Publications and recommendations of a wide range of Congressional, technical, industrial, public, and governmental groups provided input to the Task Force Study and were referenced in the Task Force Report.

After concluding that the states (through their regulatory programs) have adequately protected the public health and safety, the Task Force made a number of recommendations regarding federal versus state regulation and other related issues currently affecting commercial burial ground regulation and operation. These recommendations included development of a specific regulatory program for low-level waste disposal including regulations, standards, and criteria; and studies to identify and evaluate the relative safety and impacts of alternative low-level waste disposal methods.

The NRC staff subsequently developed a program plan for low-level waste management. To formulate this program, the staff considered the Task Force recommendations; public comments on the Task Force Report; data gleaned from review of technical documents and participation in conferences, meetings, and discussions attended by industrial, state, and public organizations; and other correspondence and documents. A document describing the program entitled "NRC Low-Level Radioactive Waste Management Program" (NUREG-0240) was published in September 1977. The availability of this document was announced in the Federal Register on December 7, 1977 (42 FR 61904). This program is currently in progress and includes technical studies to prepare a regulatory base, development of regulations, criteria, and supportive environmental impact statements as well as development of criteria and procedures for applicants to prepare license applications and for NRC to make uniform and timely licensing decisions.

3. NOTICE OF DEVELOPMENT OF A RADIOACTIVE WASTE DISPOSAL CLASSIFICATION SYSTEM

In 1974, the Atomic Energy Commission (AEC) proposed to prohibit the disposal of commercially-generated transuranic (TRU) radionuclides by shallow land burial. Upon review of the proposed rule and the comments received from interested parties, the NRC staff determined that the proposed rule was unworkable and initiated development of regulations which would govern the disposal of all radioactive waste--not just TRU-contaminated waste.

The staff initiated a study to provide a broad analytic base for a waste disposal classification system, providing a foundation for the forthcoming regulations and accompanying environmental impact statements. A document describing the classification system and applications, entitled "A System for Classifying Radioactive Waste Disposal--What Waste Goes Where?" (NUREG-0456) was published in June 1978. In an August 18, 1978 Federal Register Notice of the Development of a Radioactive Waste Disposal Classification System (43 FR 36722), the Commission requested comments on NUREG-0456 to guide the further development of the methodology and the completion of the study. Comments were specifically requested in the following areas: the overall approach; the migration pathways and exposure mechanisms; the exposure guidelines; and applications of the methodology.

A total of 17 formal comments were subsequently received on the Notice. Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received as they may relate to development of the regulation governing the management and disposal of low-level radioactive waste.

3.1 Summary of Comments

There was a varied but limited number of comments on the study relating to its use as an analytic base for developing regulations on classification of radioactive waste for disposal. Some of the commenters felt that the overall approach in the study represented a useful and needed contribution to the development of a rational nuclear waste classification system. Several commenters indicated that the models used in the study were adequate, however, this view was not shared by other commenters who cited deficiencies such as the lack of consideration of several important potential pathways and the failure to make sensitivity analyses for pathway models. Some commenters felt that the exposure guidelines were not defensible based on the rationale stated while other commenters considered them to be justified for the purposes used. There were mixed views by several commenters on the reasonableness of assumptions concerning the length of institutional control. Two commenters felt that practical problems inherent in determining radioactivity concentration or activity on a routine basis in shipments of waste to a disposal site would have to be considered in establishing a practical waste classification system. Classification of waste by sources, based on analysis of representative samples from these sources, was suggested by one of the commenters as a practical application of the methodology. Overall, the comments indicated the need for further development of the methodology to provide a practical foundation for a workable regulation on classification of radioactive waste for disposal.

3.2 Analysis of Comments in Specific Areas

3.2.1 Overall Approach

Several commenters felt that NUREG-0456 represented a useful and needed contribution to the development of a rational nuclear waste classification system.

However, one commenter stated that the report did not adequately address the concerns of the public nor demonstrate how the waste classification system would be implemented without undue burden on those directly affected by it. Several commenters felt that the methodology used to develop the classification system is only applicable to generic waste classification and not to the classification or the evaluation of any specific site. Another commenter stated that there should be an effort to systematically identify and/or project all conceivable categories of radioactive waste to include parameters such as source term, waste form, composition, concentration, activity level, radiological hazard, pathway mobility and transportability.

3.2.2 Migration Pathways and Exposure Mechanisms

Several commenters felt that the models were adequate for generating a waste classification system, however this view was not shared by other commenters. One commenter stated that the pathways used are unrealistic and the data produced is ultra-conservative and "out of touch with the real world." Several commenters noted that several important potential pathways did not appear to be considered in the methodology. One commenter expressed some concern that too much emphasis was placed upon the inadvertent intrusion scenario. Deficiencies in the area of hydrology were noted by one commenter who felt that many of the parameters selected were not representative. Several commenters noted the need for sensitivity analyses for pathway models.

3.2.3 Exposure Guidelines

Several commenters felt that the dose guidelines are not defensible based on the rationale stated. One commenter stated that while the 500 mrem/yr annual dose is supported by ICRP, the value could be 10-fold to 30-fold lower when considering U.S. national values. Another commenter noted that the exposure guidelines as used in NUREG-0456 are not conservative enough to be publicly acceptable, although they do present a very small health risk. One commenter pointed out, among other things, that there is no basis for the statement that (a) a whole-body dose-equivalent limit degree of safety, and (b) that 1 mrem/yr/GWe/yr is justified by resulting benefits. On the other hand, one commenter indicated support of the criteria used in NUREG-0456 and considered them to be justified for the purposes used. Another commenter noted that there is a need to establish acceptable dose criteria in order to carry out the methodology as presently designed. This commenter also stated that the suggested 500 mrem/yr peak individual dose rate and the 150 year period of restricted site use are reasonable provided it is emphasized that this is a standard for classification after which ALARA will be applied. One commenter stated "For the determination of de minimus concentrations, the exposure guidelines should be much lower for the sanitary land fills since they are not licensed for radiological considerations. An acceptable exposure level may be such as contained in the EPA safe drinking water regulations."

3.2.4 Applications of the Methodology

Two commenters expressed concern about the practicability of determining radioisotope concentration or activity on a routine basis in shipments of waste to a disposal site. One of these commenters suggested that the classification system should specify which of the three disposal techniques should be used for low-level solidified waste stream categories rather than specify a radioactivity concentration or activity that is permitted to be disposed of in one of these three manners. The other commenter suggested that waste sources could be generically classified by determining, based on analysis of representative samples from these sources, the range of expected activities of key isotopes and comparing these results with isotopic limits established for interfaces for the disposal techniques.

There were mixed views concerning the length of institutional control. One commenter stated that administrative control of the site for 150 years was reasonable and another commenter felt that this assumption builds a considerable degree of conservatism into the results. On the other hand, another commenter stated that people making the initial disposal decision should not plan on use of institutional assistance to maintain controls and protection beyond 100 years.

One commenter felt that some credit should be given for packaging and solidification. This commenter asked for justification of a requirement for solidification if after solidification the waste is treated, for regulatory purposes, as though it had not been solidified.

4. ADVANCE NOTICE OF PROPOSED RULEMAKING ON LLW DISPOSAL REGULATION (10 CFR PART 61)

In an October 25, 1978 Advance Federal Register Notice of Proposed Rulemaking (43 FR 49811), the Commission requested advice, recommendations, and comments on the scope and content of an environmental impact statement (EIS) to guide and support the development of a regulation, 10 CFR Part 61, for the management and disposal of low-level waste (LLW). In this Notice, the Commission identified four potential alternative disposal methods to shallow land burial; i.e., ocean disposal, engineered structures, mined cavities, and intermediate depth burial (disposal with an increased depth of cover (e.g., about 30 feet) over the disposed waste). Specific comments were requested on the following questions:

1. Proposed new 10 CFR Part 61. The Commission has concluded that an environmental impact statement should be prepared pursuant to the National Environmental Policy Act on its actions to develop more explicit criteria and regulations for low-level waste management. The Commission plans initially to consider the environmental impact of low-level waste disposal alternatives and of technical criteria for disposal of radioactive wastes by shallow land burial. An environmental impact statement will be prepared to provide an essential part of the informational and decisional base for the criteria and

rulemaking action. What significant issues should the Commission consider and analyze in-depth in the environmental impact statement? What issues are not significant, or are covered or may be covered in another environmental review, and therefore may be eliminated from analysis in this environmental impact statement? Within this statement, what should the criteria be to distinguish among viable and nonviable alternatives? Do we know enough about certain disposal options to make an informed decision at this time? Should waste segregation be applied to low-level wastes (e.g., separate disposal sites for nonfuel cycle wastes)?

2. Is it desirable to develop explicit criteria and standards for the disposal of low-level wastes? If so, what should be the general format and content of the criteria and standards?

3. What should be considered in developing the criteria for waste performance; site suitability, design, and operations; site monitoring; site decommissioning, postoperational maintenance, and funding? Are there other areas where criteria are needed?

4. What are the advantages and disadvantages of the four alternatives described above? Which of the alternatives should be given the greatest priority in development of regulations?

5. Are there viable alternatives, other than the four alternate methods identified above, which should be further considered in the development of the U.S. Nuclear Regulatory Commission's program? (Those which have been considered were noted earlier in this Notice and are discussed in greater detail in NUREG/CR-0308.)* If so, what is the basis (technical, economic, social, etc.) for considering an additional alternative as a potential candidate?

6. What should be the extent of each state's responsibility for management of the low-level wastes generated by operations within its borders?

A total of 34 formal comments were subsequently received on the Advance Notice. Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received on each specific question of the Advance Notice.

*NOTE: In NUREG/CR-0308 ("Screening of Alternative Methods for Disposal of Low-Level Radioactive Wastes"), a number of potential alternative disposal methods to shallow land burial were considered. Those methods considered to be the most viable for further study included ocean disposal, engineered structures, mined cavities, and intermediate depth burial (disposal with an increased depth of cover--e.g., about 30 feet--over the disposed waste). A followup to this report, in which these alternative disposal methods were analyzed in further detail, has also been published as NUREG/CR-0680 ("Evaluation of Alternative Methods for Disposal of Low-Level Radioactive Wastes").

4.1 Summary of Comments

The respondents to the Advance Notice strongly supported NRC's decision to develop specific criteria and standards for the disposal of LLW. There was also support among the commenters that an EIS should be prepared to provide an essential part of the informational and decisional base for the development of the criteria and standards and for the rulemaking action. Two commenters, however, did not agree with the NRC conclusion that an EIS should be prepared on its actions to develop more explicit criteria and regulations for LLW management.

The commenters were divided on the form and structure of the criteria and standards to be developed by NRC. Some commenters stated that criteria and standards should be specific and detailed. Others suggested the criteria and standards should be minimal and basic and should emphasize the performance objectives to be met by LLW disposal facilities. The commenters also stated that as part of the development of LLW disposal standards and criteria, a system was needed for classifying or segregating the waste based on hazard.

A number of comments were received on NRC's questions regarding alternative disposal methods to shallow land burial. Although the comments in this area were mixed, the most often expressed opinion was that primary consideration should be given to developing requirements for shallow land burial and emplacement of waste into mined cavities. The disposal of wastes into ocean waters was given the lowest priority. Four commenters felt there was no need to establish a priority list of the alternative waste disposal methods to shallow land burial. The most often expressed disadvantage to any alternative method was the potential for increased cost. Approximately 60% of the respondents suggested other potentially viable methods for low-level waste treatment and/or disposal. The methods mentioned most frequently were volume reduction and other advanced processing techniques.

A clear consensus of the extent of the state's responsibilities did not appear in the responses. The issue that appeared in agreement was the need for interagency and state cooperation and negotiation. Approximately half of the commenters added that LLW disposal sites should be regionally located and there was no need or desire to have one site in each state.

4.2 Analysis of Responses to Specific Questions

1(a). What significant issues should the Commission consider and analyze in-depth in the environmental impact statement?

The responses to this question were widely varied. The issues most frequently identified by the commenters were: (1) cost benefit analysis, (2) potential effluent releases, (3) geography and geology, (4) ground and surface hydrology, (5) alternative disposal methods, (6) adverse environmental effects, (7) long-term care, (8) state, local and regional conflicts, (9) demography, (10) transportation, (11) monitoring programs, (12) socio-economics, and (13) irreversible and irretrievable commitments.

Other issues that were mentioned by the commenters included: (1) seismology, (2) ecology, (3) radiological background, (4) potential mitigating measures, (5) occupational exposures, (6) onsite accident analysis, (7) alternative siting, (8) need for disposal facilities, (9) short-term vs. long-term productivity of disposal site land, and (10) socio-political issues.

1(b). What issues are not significant, or are covered or may be covered in another environmental review and therefore may be eliminated from analysis in this environmental impact statement?

The issues most frequently identified by commenters as insignificant or issues that should be addressed in other environmental reviews include: (1) transportation routing and accidents, (2) radiation exposures during transportation, (3) site-specific issues, including local ecology, (4) meteorology and climatology, and (5) air quality.

One commenter expressed the opinion that no issue should be dismissed as a priori insignificant.

1(c). Within this statement, what should be the criteria to distinguish among viable and nonviable alternatives?

Comments were sparse on this question and a clear consensus of criteria could not be obtained. One possible explanation was a problem with interpretation of the question--e.g. alternatives to be addressed in the EIS vs. the NRC study of alternative disposal methods. The issues that were mentioned most frequently were that disposal sites should be consistent with public health and safety, site operation be an economic benefit, and a comparison should be made of long-term effects and costs of different alternatives. Three commenters stated that the EIS should not attempt to develop such criteria. One of these commenters also stated that such a decision would discourage innovation and improvement of the alternative disposal methods.

1(d). Do we know enough about certain disposal options to make an informed decision at this time?

Of those who commented on this question, about 40% stated that most of the available information was on shallow land burial and an informed decision could probably be made on this disposal method. Three commenters stated that there was sufficient information on all four alternatives to shallow land burial (intermediate land burial, mined cavities, ocean disposal, engineered structures) to make an informed decision after a careful review of each option. Four commenters felt that there was not enough information available to make an informed decision on any of the four options. One of these responders stated "I believe nobody knows this answer for sure. The history of waste management has not been a glorious one. Much of our behavior has been to get the low-level waste out-of-sight and out-of-mind rather than to determine the consequences of our behavior."

1(e). Should waste segregation be applied to low-level wastes (e.g., separate disposal sites for nonfuel cycle wastes)?

Of the responders who commented on this question all but one commenter stated a need for development of a waste classification or segregation policy.

2(a). Is it desirable to develop explicit criteria and standards for the disposal of low-level wastes?

Comments received on this question reflected general support for developing explicit criteria and standards for disposal of low-level waste. Three commenters stated that either explicit criteria are not required or that the criteria and standards should be kept to a minimum.

2(b). If so, what should be the general format and content of the criteria and standards?

The major issues identified by commenters for which explicit criteria and standards were needed included (1) characteristics and performance standards of the waste to be buried, and (2) performance of the disposal method. Other criteria needs frequently mentioned by the commenters include criteria for public health and safety, the ALARA concept, radiation monitoring, recordkeeping, security and safeguards, and environmental studies of specific disposal sites. Several commenters expressed a need for flexible criteria to allow the use of future technologies. Finally, at least two commenters stated that the criteria should stipulate performance standards to be met by disposal methods rather than stipulating specific requirements (e.g., depth of ground-water table, amount of rainfall) for individual disposal methods.

3(a). What should be considered in developing the criteria for waste performance; site suitability; design and operations; site monitoring; site decommissioning, postoperational maintenance, and funding?

The responses to this question were somewhat sparse and scattered, making it difficult to perform a conclusive analysis.

Waste Performance. There were several comments regarding the importance of specific criteria for waste form and packaging for disposal, but few comments on the considerations important to formulating these criteria. Considerations suggested included the chemical stability of the waste as well as the half-life of the radioactive material contained in the waste.

Site Suitability. A majority of those who responded to this question stated four important considerations to site suitability: remoteness, geologic stability, surface and groundwater hydrology, and the ability to enhance containment. Other considerations mentioned by commenters include meteorology, seismology, and radiation background. The commenters were divided on whether population density should affect site suitability. Finally, one commenter stated that site suitability must be weighed against other hazards such as transportation.

Design and Operations. In response to this question, seven commenters stated that the criteria for site design and operations should be one that requires a high degree of containment of the waste. Other considerations mentioned by the commenters included proper packaging, provisions for security and safeguards, provisions for leakage monitoring, and well-defined duties of site personnel.

Site Monitoring. Seven commenters suggested that criteria for site monitoring should include criteria for equipment for detection of potential radionuclide migration by various pathways. Other considerations mentioned by commenters included redundant monitoring systems, a system for waste accountability at the site, and the need for precise instrumentation.

Decommissioning, Postoperational Maintenance. Four responses were received from the public. Of these responses, unanimous support was expressed for a criterion that would state that a disposal site, following closure, would meet a preexisting radiation level with minimal maintenance required. Three commenters suggested that the term site closure should be used in place of the term site decommissioning.

Funding. Three commenters responded to the question regarding specific funding criteria. All of these commenters suggested that funding should be on a user's fee basis.

3(b). Are there other areas where criteria are needed?

Six responses were received which stated that specific radiation dose guidelines need to be established. Other areas where specific criteria were suggested include recordkeeping, waste acceptance criteria, retrievability and isolation, and public acceptance of a disposal site.

4(a). What are the advantages and disadvantages of the four alternatives described above (the four alternative disposal methods to shallow land burial--intermediate land burial, mined cavities, ocean disposal, and engineered structures--identified as most viable in NUREG/CR-0308)?

Fewer than half of the 34 respondents offered comments on all the four alternative disposal methods. A majority of these commenters simply stated a preference for or against a particular disposal method and did not comment on the advantages or disadvantages of the method.

Engineered Structures. Of those who commented on this question, 60% stated a favorable opinion to the emplacement of wastes in engineered structures. The major advantages perceived by the commenters appeared to be (1) ease of recovery, and (2) monitoring capability and safeguard mechanisms can be designed into the structure. As expressed by one commenter, the disadvantages are that above ground structures appear to be an interim rather than a permanent solution and below ground structures would entail an unnecessary complication and expense for use for low-level waste.

Ocean Dumping. Half of the respondents offered a comment on ocean dumping. Most of the comments were against ocean dumping as an alternative method of low-level waste disposal. The major perceived disadvantages are the probability of severe ecological damage, international repercussions, and the issue of dispersal versus containment. The only advantage seen by the respondents appeared to be the comparatively lower cost and ease of disposal. Finally, one commenter stated that it would be illegal and duplicative for the Commission to develop any regulatory program for this alternative disposal method.

Mined Cavities. The comments on this issue were very sparse; thus, a firm conclusion on the commenters' perceptions of the advantages and disadvantages of mined cavity disposal is difficult. Most of the commenters on the potential emplacement of wastes in mined shafts supported this disposal method. The major advantage appeared to be the retrievability of the waste. However, many commenters felt that the method of mined cavities would involve unnecessary expense for use of low-level wastes.

Intermediate Land Burial. The commenters who offered an opinion on this potential disposal method were divided. The comment offered most frequently was that the bulk of the waste would be contained longer, but the increased cost would not be justified by the relatively insignificant benefit.

4(b). Which of the alternatives should be given the greatest priority in development of regulations?

Sixty percent of the respondents offered comment on the question of setting priorities. The majority of these commenters stated that primary attention at this time should be given to establishing criteria for shallow or improved shallow land burial. Approximately one-fourth of the commenters supported the emplacement of wastes in mined cavities and only one commenter felt that priority should be given to ocean dumping. Finally, four commenters generally agreed with one commenter who stated that "the underlying objective of any method of disposal is to keep the waste from entering the biosphere. There is no reason to believe that more than one disposal method could not satisfactorily perform this function."

5(a). Are there viable alternatives, other than the four alternative methods identified above, which should be further considered in the development of the U.S. Nuclear Regulatory Commission's program?

Approximately two-thirds of the commenters commented on this issue. The three alternatives most frequently mentioned were volume reduction and other advanced processing methods, segregation and classification systems, and a de minimus category of wastes. However, none of these three options were mentioned by more than 25% of the commenters. Other potential alternatives mentioned included: (1) solidifying waste into concrete within stainless steel welded liners which are then buried in impermeable clay; (2) reprocessing; (3) shooting rockets filled with waste into the sun; (4) mines sited in desert areas; (5) deep well injection and hydrofracturing; (6) mixing, dilution and dispersion; (7) ocean disposal with reinforced concrete vessels; (8) the use of an increased number and kind of man-made barriers; and (9) a combination of two or more methods. Three commenters felt that there appeared to be no other viable alternatives to the four previously mentioned alternatives.

5(b). If so, what is the basis (technical, economic, social, etc.) for considering an additional alternative as a potential candidate?

The comments received were sparse on the basis for the other viable alternatives. One commenter felt that a combination of advanced processing techniques and disposal on federal lands (which are badly contaminated and beyond the possibility of cleanup) would have the advantage of utilizing the most advanced processing techniques, have the capacity to handle other forms of hazardous wastes, and most importantly would spare public lands.

Another commenter stated that the development of transmutation procedures, solar technologies and sending waste rockets into the sun should all be considered long-term options. Two commenters suggested that volume reduction and a definition of radioactive waste plus a prohibition of burial of material which is only suspected of being contaminated would tend to reduce the volumes of burials. One commenter stated that incineration appears to be the best disposal method for flammable and toxic organic solvents and such waste could be used as a fuel source for large incinerators. Another commenter stated that ocean disposal with reinforced concrete vessels offers a more secure means for collection and transport of low-level wastes.

6. What should be the extent of each state's responsibility for management of the low-level wastes generated by operations within its borders?

A clear concensus of the extent of the state's responsibility did not appear in the responses. About 60% of the commenters responded to this question. Of these, about one-third felt that each state was responsible to pay for the disposal of the waste their state's utilities have generated. Approximately half of the commenters stated that the low-level waste burial sites should be located regionally and not on a state-by-state basis. Several felt that safe disposal of low-level waste was the responsibility of the federal government. Half of the commenters stated the necessity for interagency and state cooperation and negotiations. Several of the commenters felt that licensing and management, siting, environmental monitoring, operations and decommissioning of the burial facility should reside with the state.

Most felt the states should also have an option to transfer regulatory control to the government if and when desired. However, approximately the same number of commenters stated that the government should control licensing, siting, monitoring, and operations of the low-level waste burial facilities. Finally, one commenter stated that "NRC...is responsible for every bit of nuclear waste generated in this country."

4.3 Miscellaneous Comments

In reference to the Federal Register Notice, several of the commenters suggested that it is important for NRC to make clear that these "recent developments" do not reflect that any hazard to public health and safety has resulted from shallow land burial operations. One commenter stated that low-level waste is very dangerous and small amounts of radiation can be carcinogenic. Finally, one commenter expressed a concern that "the NRC schedule for the development of a regulatory program for shallow land burial by 1980 and one alternative by 1981 may be premature in view of the amount of research necessary. Much critical technical information on site selection, waste treatment and packaging, possibilities for segregating wastes, etc., presently being conducted by DOE, USGS, NRC, and EPA will not be available at an early enough date."

5. NOTICE OF AVAILABILITY OF PRELIMINARY DRAFT REGULATION 10 CFR PART 61 FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

The comments received by NRC on the Advance Notice were utilized by NRC staff in scoping the form and content of an EIS and LLW disposal regulation. To help focus development of the draft EIS and proposed LLW disposal regulation, NRC staff prepared a preliminary draft regulation 10 CFR Part 61 (draft dated November 5, 1979). The November 5 preliminary draft regulation received wide distribution and copies were sent to state liaison officers, federal and state agencies, industry, public interest groups, and others. Comments received are being considered in the further development of the proposed regulation and draft EIS.

In a February 28, 1980 Federal Register Notice of Availability of Preliminary Draft Regulation 10 CFR Part 61 for Disposal of Low-Level Radioactive Waste (45 FR 13104), the Commission requested comments on the preliminary draft regulation of November 5, 1979 to be considered during further development of the regulation, preparation of the EIS, and preparation of regulatory guides. In this notice the Commission indicated its interest in establishing a de minimus level (a level of radioactivity in waste that is sufficiently low that the waste can be disposed of as ordinary nonradioactive trash) for short half-lived radioisotopes commonly used in medical, research, and other applications--although this concept was not reflected in the November 5 version of the preliminary draft regulation.

The objectives that the staff had in mind at the time of this notice and which are reflected by the preliminary draft regulation are the following:

1. That LLW disposal facilities are sited, designed, operated, and closed to assure the long-term confinement of the disposed waste with essentially no need for active long-term site maintenance following closure.

2. That the regulation is applicable to a range of potential LLW disposal methods, particularly those investigated in detail during NRC's study of alternative disposal methods to shallow-land burial. These methods include improved shallow-land burial, intermediate land burial (i.e., disposal with about 30 feet of cover material), engineered structures, and mined cavities. Specific guidance for specific disposal methods would be addressed in regulatory guides or appendices to the regulation.

3. That general requirements are in the form of performance objectives, which establish what should be achieved in the disposal of LLW rather than specifying detailed technical specifications for individual disposal methods.

4. That the regulation provides numerical guidance to the extent practical.

5. That the regulation addresses: (1) administrative procedures and institutional considerations; (2) radiological performance objectives; (3) waste form and content; (4) site selection and suitability; (5) site design and operations; (6) environmental monitoring; (7) site closure (decommissioning) and funding; and (8) site surveillance after site closure.

6. That ground-water quality is protected. In preparing the preliminary draft regulation, NRC staff made use of the National Primary Drinking Water Standards for this purpose. This approach is based upon consideration of EPA's proposed regulation 40 CFR Part 250 (December 18, 1978, 43 FR 58946-59028) for the safe disposal of nonradioactive hazardous waste.

7. That protection is provided for the potential unintentional reclaimer to an LLW disposal site. Applicable concepts and methodology for this have been developed through NRC's waste classification study. By applying this methodology, the advantage of particular disposal methods for assuring confinement of particular types and forms of LLW during their hazardous lifetime would be identified.

8. That the use of multiple barriers (natural and man-made, such as waste packaging form, and content) to radioactive waste movement and human contact with waste is emphasized.

9. That the regulation is compatible with standards, criteria, and regulations promulgated by the EPA, including those standards, criteria, and regulations of the EPA Office of Solid Waste and the EPA Office of Radiation Programs.

A total of 33 formal comments were subsequently received on the preliminary draft regulation (draft dated November 5, 1979). Copies of the comments were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61. A summary of the comments received by the Commission is included below, followed by an analysis of comments received on specific sections of the preliminary draft regulation.

5.1 Summary of Comments

There was a wide range of comments concerning the overall content of the preliminary draft regulation. In contrast, all of the comments on the de minimus issue supported establishing de minimus levels for short-lived radioisotopes commonly used in medical, research, and other applications. Some commenters felt that a regulation as complex and restrictive as this one was not justified and would significantly increase waste disposal and operating costs without speeding up the licensing process. Several individual commenters thought that the regulation was too general and lacking in sufficient specificity, particularly in various technical aspects such as waste performance and technical requirements for an LLW disposal facility. Some commenters on waste performance expressed concern that requirements for solidification may be inflexible to some extent, unnecessarily restrictive when applied to institutional waste, and at cross purposes with requirements for volume reduction. Several of the commenters addressed the need for greater specificity for release and exposure limits as well as clarification of vague provisions concerning site investigation, hydrogeology, and surface geology. Several commenters felt that state government should be afforded a greater role in the regulation of LLW disposal in areas such as site selection, testing, inspection, and enforcement. There were mixed views by several commenters on the reasonableness of requirements for site funding. Several commenters took issue with the proposed maximum license period and questioned the technical basis for the period of postclosure observation and maintenance. Overall, the comments generally agreed with the approach and general content of the preliminary draft regulation. They also indicated a need for further improvement in the preliminary draft regulation so that, ideally, the final version will be plainly written in unambiguous, concise language stating clearly defined and scientifically-based requirements that will, in a cost-effective and balanced manner, provide reasonable assurance of LLW confinement, encourage meaningful state participation, and allow timely review and approval of licenses consistent with protection of the public health and the environment. While this goal is formidable, none of the commenters indicated any unsurmountable barriers to its achievement.

5.2 Analysis of Comments on Specific Sections of Preliminary Draft Regulation

5.2.1 Analysis of "SUBPART A: GENERAL PROVISIONS"

61.10 Purpose

The only commenter on this section suggested that it specifically state that the regulations are intended to promote the efficient use of any newly licensed burial capacity.

61.12 Scope

The only commenter on this section suggested that it should address "brokers" and others who may perform decontamination or dismantling for others but use their own license.

61.14 Definitions

A majority of the comments addressed the need for the definitions of several of the terms to be clarified. The most commonly cited terms were low-activity bulk solids, candidate sites, disposal, low-level waste (LLW), site monitoring, waste solidification, and free-standing liquid. Several commenters were concerned by the requirement of at least 3 alternative sites in the definition of slate of candidate sites. One commenter addressed the need for clarification of other terms such as decommissioning, engineered barriers, and environmentally preferred alternative site. Another commenter felt that the duration of funding and an inflation factor should be considered in the definition of funding for decommissioning, postoperational maintenance, surveillance and monitoring. Individual commenters suggested the need for definitions of additional terms such as homogeneous, low-level resins, high-integrity containers, dewatering, LLW disposal site, and de minimus.

61.20 General disposal requirement

Several comments were directed toward the issue of federal or state ownership of low-level waste sites. One of these commenters felt that the language implied a mandatory transfer of control of low-level waste sites from the state to the federal government. Several commenters did not agree with the provision that waste sites should be sited only on federal or state lands. One of these commenters cited the case of deep LLW disposal wells utilized for private industrial use. Another commenter felt that the siting criteria should permit siting anywhere but that title must be transferred to state or federal government prior to issuance of a license. This commenter also suggested that transfer of low-level waste include additional authorized recipients as provided in 10 CFR Part 71. Several commenters asked for clarification of the purpose and extent of the buffer zone area of the disposal facility. Other commenters noted the need to address the issue of mineral rights at the site.

61.22 Exemptions

Several commenters felt that this statement was too broad and that it was not clear on what basis exemptions will be granted. One commenter suggested that exemptions should be emergency based and only when an emergency exists as declared by the President or the Commission itself.

5.2.2 Analysis of "SUBPART B: LICENSE APPLICATION AND ACTIONS ON APPLICATIONS"

61.24 Activities requiring license

The only commenter on this section stated that it seems to include others besides disposal site operators within its scope which would appear to be unnecessary in that they are adequately treated in other parts of Chapter 1 of 10 CFR.

61.26 Notice of intent

Several commenters questioned the purpose of this section. One commenter stated that the affected state should also be notified. Another commenter felt that the method used for early identification of siting activities to ensure participation by all interested parties might be counterproductive. Opinions were expressed by individual commenters that the difference in the months to docketing of an application (1) was difficult to understand and (2) would have the sole result of delaying the time to issuance of a license for a low-level waste disposal facility. Several commenters felt that the requirements for a general description of the decision process used to select the region of interest and the slate of candidate sites needed clarification; one commenter questioned the need for 3 alternative sites in the slate of candidate sites. Another commenter noted the need for clarification in the requirements for (1) the summary description of the proposed project and (2) the description of the applicant's plans to involve state and local government.

61.28 Application for license--financial information

Several commenters thought that the provisions were appropriate and necessary but the need for clarification of ambiguities and the lack of specificity was noted. One commenter felt that the financial amounts involved appear to be reasonable, however several other commenters thought that the requirements for funding seemed prohibitively expensive. Several commenters questioned the basing of a financial charge (to be borne by the site owner) on costs of 100 years of postoperational surveillance and monitoring. One commenter stated that these regulations should exempt any byproduct waste systems that can exhibit adequate long-term containment from requirements for ownership transfer, site inspections, and long-term surveillance fees. Another commenter stated that (1) any perpetual care and maintenance program or closure plan should be left to the government agency which owns the site and the lessee as a matter of contractual negotiation, (2) it is not known whether such surety arrangements are available, and (3) a 1% real rate of interest is unrealistic; however, 2% is a more reasonable figure and justifiable on historic grounds.

61.30 Application for license--safety and environment report.

Several commenters questioned the need for diversity in an applicant's slate of candidate sites. Individual commenters expressed concern over several aspects of information requirements for the disposal facility and its operation including (1) specification of radioactive material, (2) description and analysis of the site, (3) use of engineered and natural barriers, (4) emergency planning, (5) alternative uses of the facility, (6) trained facility personnel, (7) gaseous and liquid effluent control equipment, and (8) state and local government involvement. One commenter felt that additional information should be required regarding nonradioactive toxic and hazardous substances. Another commenter stated that some requirements should be given for the operation of incinerators as well as for calciners. Another commenter felt that the emphasis on NRC decisions as to which multiple site will be used is inconsistent with good regulatory practice which says that regulators will approve, make recommedations or disapprove a proposed applicant action but will not make decisions for an applicant.

61.32 Application for license--site operations manual

A commenter felt that requiring NRC approval of a site operations manual and all changes thereto would delay implementation and discourage initiative toward routine improvement of the manual and its procedures. Another commenter asked if this section restricts periodic changes to properly update the manual to current operational and safety practices or must these necessary changes await the normal long time frame approval process.

61.34 Application for license--site closure and decommissioning plan

One commenter on this section thought that it is an excellent idea to require at least a preliminary plan at the time of license application thereby providing a common basis from which the licensor and licensee can work. Another commenter felt this should not be a separate application but should be part of the operational license application and be invoked at the discretion of the owner and operator acting in concert.

61.36 Filing of applications for licensees; oath or affirmation

One commenter on this section felt that the requirement for 150 copies of the safety and environmental report seemed arbitrary and unnecessary. This commenter suggested that the requirement be standardized at 25 copies each of the necessary documents. Another commenter felt that if a generic finding on the Commission's part is intended that security plans are exempt as stated in footnote (c) then that should be made clear and not be an additional burden placed on the licensee to make application and justification thereof.

5.2.3 Analysis of "SUBPART C: PARTICIPATION BY STATE GOVERNMENTS"

One commenter stated that this subpart restricts the role of state governments in siting and that their role should extend considerably beyond facilitating local government and citizen participation. This commenter expressed specific concerns in this regard in sections of this subpart dealing with (1) filing of proposals for state participation, (2) approval of proposals, and (3) assistance to Agreement States. Another commenter requested clarification of aspects of the above sections as well as another section of this subpart concerning early notice. Other individual commenters stated that (1) the NRC should retain the authority to license waste disposal sites on federally-owned land and (2) licensing or approval to store radioactive wastes generated at a nuclear plant site should rest with the NRC.

5.2.4 Analysis of "SUBPART D: CONDITIONS AND ACTIONS ON LICENSE"

61.52 Issuance of licenses

Individual commenters expressed opinions that (1) the applicant's plans for coping with emergencies include chemical as well as radiological contingencies, (2) postoperational maintenance must include the provision for extended site monitoring to ensure proper containment of wastes, (3) the applicant's postclosure plans address such matters as forestry resource uses and any necessary limitations on uses, (4) this section may preclude Agreement States from licensing burial facilities, and (5) this section infers the possibility that a construction permit may be issued separate from and prior to the issuance of an operating license.

61.54 Receipt of waste

One commenter noted that the notification of the Commission by the licensee prior to receipt of waste was too open-ended with respect to reporting results of demonstration programs carried out to confirm the adequacy of design. Another commenter stated that states ought to be able, with permission of Congress, to limit where waste comes from.

61.56 General license conditions

One commenter on this section questioned whether it precluded Agreement States from licensing burial facilities. Another commenter inquired as to the provisions for financing, operating, and managing a facility upon revocation of a license. Another commenter asked (1) if the requirement for Commission consent in writing, in the form of a license amendment, to a license transfer precludes a licensee from going out of business or declaring bankruptcy, and (2) if the requirement for an NRC-approved program covering the training of facility personnel applies to Agreement States.

61.58 Specific license conditions

One commenter felt that this section is too vague because it does not state acceptable criteria or numerical guidance for the categories of license conditions considered. Another commenter suggested that restrictions as to physical and chemical form and radioisotopic content and concentration of radioactive waste include requirements on segregation of particular kinds of waste by reactivity level and chemical and isotopic composition. Another commenter suggested that restrictions as to the amount of waste permitted per unit volume of emplacement space include radioisotopic in addition to physical and chemical characteristics of the waste.

61.60 Changes, tests, and experiments

One commenter stated that (1) the prior notification requirements for changes in operating procedures is of no real benefit and unnecessarily restrictive, and (2) some of the criteria for prior Commission approval of changes, tests, and experiments are inappropriate and ambiguous. Another commenter suggested that appropriate state agencies should receive copies of the report prepared by the applicant for NRC on changes, tests, and experiments. Another commenter stated that this section was well thought out and workable but appeared to conflict with Section 61.32.

61.62 License renewals.

Several commenters felt that the maximum license period of five years seemed unduly restrictive while requiring a summary report of disposal quantities every five years appeared to be too liberal. These commenters felt that once a site is properly licensed and operated, it will be able to continue to operate over its projected lifetime. Another commenter suggested that appropriate state agencies should receive copies of the report submitted by the applicant to the Commission.

61.64 Amendment of license

One commenter suggested that appropriate state agencies should receive copies of the application for amendment to a license filed with the Commission.

61.66 Application for closure

One commenter suggested that this section would not be as open-ended if specific licensing conditions were stated. Another commenter suggested that appropriate state agencies should receive copies of the application to amend the license for closure filed by the applicant. A third commenter felt that the information submitted in this application should include compatible and incompatible land uses. Another commenter questioned the need for an application and stated that (1) all of this information should be committed to the initial closure plan and (2) the licensee should notify NRC of its intent to implement closure.

61.68 Postclosure observation and maintenance

Several commenters questioned the technical basis for the requirement of a minimum of 5 years for the period of postclosure observation and maintenance. Another commenter stated that the 5 year observation and maintenance period (especially maintenance) is far too short. One commenter did not feel once injection has ceased for a particular disposal well that postclosure observation should be initiated, much less for a period of 5 years. This commenter felt that such disposal wells should be plugged and abandoned in a fashion similar to other industrial disposal wells.

61.70 Termination of license

One commenter felt that clarification was needed for the stipulation that reasonable assurance has been provided by the applicant that the site requires only passive case by the site owner with minimal need for active site maintenance. Another commenter suggested that funds need only be available, not transferred, to the site owner. One commenter suggested that plugging and abandonment procedures for the termination of an LLW disposal well be incorporated within the license.

5.2.5 Analysis of "SUBPART E: TESTS, INSPECTION, AND ENFORCEMENT"

61.72 Tests at licensed disposal facilities

Several commenters felt that there ought to be some test of reasonableness in the tests the Commission may require. One commenter stated that such tests must be permitted to interface with operations or utilize site operator personnel unless NRC pays for the service or loss of business. Another commenter stated that the affected state (regardless of its status as an Agreement or non-Agreement State) must be allowed to do its own monitoring and inspection. Thus the appropriate state agencies would also need site access authorization.

61.74 Commission inspections of disposal facilities

Several commenters suggested that the inference that disposal of waste will be inspected should be removed. Two other commenters felt this section should also authorize state inspection.

5.2.6 Analysis of "SUBPART F: MANIFESTS, RECORDS, REPORTS, QUALITY ASSURANCE, AND AUDITS"

61.78 Manifests

Individual commenters expressed concern about several aspects of the manifest including (1) purpose, (2) format, (3) specificity of data recorded, (4) flexibility of the certification statement, and (5) distribution of copies. One commenter asked how this section would apply in a situation where the operator of the LLW disposal site is the sole generator of the waste. Another commenter stated that any manifest required under NRC regulation should be uniform across all sites, even those in Agreement States, and should be compatible with existing DOT and EPA regulations.

61.80 Maintenance of records and reports

Several commenters expressed divergent views as to the extent of distribution, prior to license termination, of copies of records of the facility location and the quantity of LLW contained in the facility. One commenter suggested that a copy of the annual financial report should also be sent to the appropriate state agency. Individual commenters stated that the requirement for filing of certified financial statements (1) is wholly unjustified, and (2) may pose problems for companies which may treat such statements as proprietary information. Another commenter felt that records kept by the disposal facility operator should also include accurate maps and descriptions of buried trenches or other disposal installations.

61.82 Quality assurance program

The only commenter on this section raised the question as to whether or not a written quality assurance plan would be required.

61.84 Audit requirements for disposal facility operators

The only commenter on this section suggested that the record of the audit program should also be available for state inspection.

5.2.7 Analysis of "SUBPART G: WASTE PERFORMANCE"

61.86 Waste form and packaging

Many of the comments addressed the need for clarification of vague provisions and for definitions of several terms including free-standing liquid, disposal facility, high-integrity containers, homogeneous, low-activity, monolithic, noncorrosive, and container.

The issue of waste solidification received considerable attention from commenters. Several commenters felt that the criteria identified are a step in the right direction. One commenter suggested that packaging requirements for LLW should be consolidated in a single section concerning compaction, solidification of liquids, inactivation of biohazards and similar matters. Other commenters stated that a very careful technical analysis is needed to justify solidification of all LLW in general and of dewatered resin in particular. One of these commenters felt that free-standing liquid requirements for dewatered resins were too stringent to be met practically thereby eleiminating the potential use of high integrity containers and leaving solidification (at significant increase in cost) as the remaining option. Mixed views were taken on the prohibition against immobilization of liquids by only the addition of absorbent materials. However, most of the commenters who disagreed with this provision felt that it was unnecessarily restrictive when applied to institutional wastes. One commenter felt that requiring institutional waste to be in a free-standing form is unnecessarily too restrictive. Several commenters expressed concern over provisions excepting some liquids from solidification requirements when there is specific Commission authorization. In this regard, individual commenters thought that these provisions were too inflexible and should be relaxed to allow consideration of disposal of (1) contaminated oil, and (2) low-level radwaste water into deep disposal wells. Several commenters felt that dry compacted trash should be clearly exempted from the requirement to be in free-standing form. Several commenters felt that application of transportation criteria to waste packages might be irrelevant or unreasonable. One commenter suggested that every attempt should be made to minimize regulations, and particularly, conflicting requirements between DOT and NRC regulations. Individual commenters expressed concern over several other provisions related to physical, chemical, radiological, and biological properties of waste forms accepted for disposal. Other individual commenters suggested that (1) individual glass melting technology be considered and (2) guidance should be given on leachability as well as radiation stability of solidification agents.

61.88 Volume reduction

Individual commenters felt that this section was vague and should contain specifics such as minimum allowable density, types of compactors, etc. One commenter stated that this section should apply at the source of the waste rather than at the disposal site. Individual commenters expressed a concern that requirements for volume reduction may be at cross purposes with requirements for solidification. Another commenter noted that existing regulations or guides regarding dose rate or curie control limitations may preclude volume reduction by any of the existing methods.

61.90 Content of LLW

One commenter asked if a minimum level of radionuclides would be specified. Individual commenters expressed concern that restrictions on chelating agents were unrealistic and could preclude LLW disposal facilities from accepting reactor waste.

5.2.8 Analysis of "SUBPART H: TECHNICAL REQUIREMENTS FOR AN LLW DISPOSAL FACILITY"

61.94 Long-term performance objectives

One commenter felt that there was a contradiction between the concept of containing LLW while at the same time allowing for compliance with existing or proposed release limits. Other commenters suggested greater specificity for release and exposure limits as well as clarification of site maintenance. Another commenter suggested that some recommendation should be made as to how contaminant levels in ground water and potential exposures to individuals should be calculated. One commenter felt that the duration of institutional controls following termination of the license could be left to the discretion of the applicant so long as performance objectives were met.

61.96 Site suitability

Several of the commenters addressed the need for clarification of (1) vague provisions concerning site investigation, hydrogeology and surface geology, and (2) several terms such as complex site, reasonable assurance, unseated fault, and capable fault. Other commenters felt that undue emphasis has been placed on ground-water transport as a major pathway. A provision prohibiting siting in areas subject to significant geologic processes came under heavy criticism from several commenters for being too restrictive and poorly worded. Another provision singled out by several commenters for criticism (such as lack of necessity and rationale) related to prohibiting siting in areas having unacceptable seismic activity. One commenter felt that the requirement to not mask the environmental monitoring and surveillance program may preclude the colocation of a disposal facility with other nearby nuclear facilities. One commenter noted that a prejudgment concerning adverse effects of ground-water intrusion should be avoided since it presumes that stated performance objectives cannot be met if such a ground-water intrusion should occur. Another commenter suggested restructuring of the provision concerning adverse effects of ground-water intrusion, taking into account disposal of low-level radwaste water by injection into ground-water aquifers (deep wells).

61.98 Facility design and operation

Many of the commenters addressed the need for clarification of some vague provisions and terms such as "specified limits" and "minimize." Individual commenters requested clarification of provisions relating to (1) release of nonradiological noxious materials from the facility, (2) design of the facility to enhance and improve the ability of natural site characteristics to confine the waste after disposal, (3) implementation and maintenance of a site-surveillance program, (4) inspection of incoming packages, and (5) controls and procedures for maintenance of a site-specific training program. One commenter noted that daily inspections should be on workdays only and not on holiday or weekend periods. Another commenter felt that the educational and safety criteria for employees at LLW disposal facilities should be those already established in 10 CFR Parts 19 and 20. One commenter noted that many of the operational aspects in this section will require coordination with appropriate state agencies.

61.102 Environmental monitoring--applicant

Several commenters took differing views with regard to the duration of a preoperational monitoring program. One commenter stated that a period of 1 year prior to any major site construction is overly restrictive while another suggested 3 years as the appropriate time. Another commenter felt that the requirement for 1 year of data is reasonable, provided site construction is allowed during this period. One commenter was concerned as to what action levels for the monitoring program are left up to the applicant. Another commenter suggested that this program and results should be coordinated with appropriate state agencies. One commenter felt that the requirement for an environmental monitoring program is applicable for shallow-land burial of radwaste but not necessarily applicable for the deep disposal well method.

61.104 Site closure and stabilization

The comments were addressed principally to the need for clarifying the terms background level and buffer zone. One commenter asked if some sort of duplicate land use recordkeeping system was preferable to a stable long lasting marking device to indicate the location and nature of the LLW disposed of in the facility. Another commenter requested clarification of the provision for a monitoring program on federal land with regard to (1) financial responsibility, and (2) federal-state relations. One commenter asked why it is necessary to provide financial surety arrangements as contained in 61.28 if, as this section implies, a site can be shown to exhibit long-term containment integrity.

5.2.9 Analysis of "SUBPART I: PHYSICAL SECURITY"

One commenter suggested that physical security provisions should be required after site closure as well as during site operations. In this regard, another commenter requested clarification of the provision for fencing (passive barrier) after plant decommissioning. One commenter felt that the provision for communications with law enforcement agencies was too vague. Another commenter stated that the hazard present at a deep disposal well site is minimal from a radiological standpoint and does not justify provisions for, essentially, continuous monitoring of the site.

5.2.10 Analysis of "SUBPART J: REQUIREMENTS ON WASTE PROCESSORS AND INDEPENDENT WASTE PROCESSORS"

Individual commenters stated that (1) regulations concerning radioactive waste packaging by licensees should be placed in 10 CFR Parts 20, 40, 50 and 70; NRC should deal with waste processor requirements when it handles the processor's license--not when a disposal company is attempting to obtain a license; (3) waste generators solidify all liquid wastes by methods that will leave no free liquid; (4) all disposal sites should also be processing sites; and (5) the chief means for volume reduction should be incineration of combustibles with subsequent burial of immobilized ash.

61.112 Operating procedures

Individual commenters noted that requirements for solidification in operating procedures and controls and in measurement and control programs may not be appropriate for all waste categories, i.e., trash.

61.114 Tests

One commenter stated that this section is vague and needs specifics. Another commenter felt that a test for reasonableness should be added.

61.116 Audits

One commenter suggested that copies of audits should be sent to the appropriate state agencies. Another commenter stated that waste generators (1) advise the Commission one month in advance of any packaging of waste so that Commission inspectors may observe their packaging operations, and (2) submit to the Commission a QA program to assure conformance of their waste quality and packaging methods with the requirements of Subpart G.

5.2.11 Analysis of "MISCELLANEOUS COMMENTS"

5.2.11.1 Overall Approach

Individual commenters stated that the general approach in the regulation is encouraging and that it should be written in plain language, eliminating unnecessary repetition, and stating requirements that would (1) be clearly defined and based on scientific requirements providing reasonable assurance of LLW confinement; (2) encourage state participation by including detailed descriptions of the interaction processes with state governments with equal treatment for Agreement and non-Agreement States; and (3) allow licenses to be reviewed and approved in a timely manner consistent with protection of the public health and environment. Other individual commenters felt that (1) the need for regulations as complex and restrictive as those proposed was not established; and (2) the regulations would not speed up the licensing process and would increase significantly waste disposal and operating costs. Several individual commenters suggested consideration of alternatives to the draft regulation such as regional waste disposal sites and processing centers; above ground storage for low concentration, short half-life radioactive material; and alternatives to shallow land burial such as volume reduction and engineered-type storage facilities. One commenter felt that the regulations in their present form will have significant impact on deep injection well disposal of low-level radioactive waste water generated by in situ leach uranium facilities.

5.2.11.2 Technical Content

Individual commenters stated that the regulation was too general and lacking in sufficient specificity in technical aspects such as earth sciences, hydrogeology trench capping methodology and requirements for solidified waste. One commenter stated that the proposed regulation does not provide sufficient flexibility for a waste producer to bury its waste at the site of origin. Other individual commenters felt that (1) a systems approach that can take advantage of present geotechnical knowledge should be used instead of the arbitrary limitation approach; (2) performance objectives should be accompanied by recommended or required methods for demonstrating compliance while avoiding prejudgment of what specific site properties will meet the performance objectives; and (3) the concept of containing LLW while at the same time allowing for compliance with existing or proposed release limits is somewhat contradictory. Several commenters stated that the rule should place more emphasis on measures to restrict onsite reclaimer activities rather than on controlling offsite transport by ground water or erosion. One commenter felt that the regulations ought to require categorizaion (segregation) at the origin and that all waste disposal sites should also be waste processing sites. Another commenter stated that (1) if the intent for the proposed regulations is to apply transport requirements in addition to disposal requirements, it should be clearly stated; and (2) the requirement that evaporator bottoms, filter sludges, resins and sludges all be immobilized by solidification may not always be needed.

5.2.11.3 De Minimus Levels

All of the commenters addressing this issue felt that de minimus levels should be established for short half-lived radioisotopes commonly used in medical, research, and other applications.

5.2.11.4 Institutional Wastes

One commenter stated that (1) there is no need to attempt to solidify the low activity and low volume liquid wastes generated by hospitals and medical research institutions; (2) alternative techniques such as decay, diffusion and incineration should be used when possible to do so safely; and (3) packaging regulations should not be "over-engineered" for institutional waste so as to treat it as though the hazard were equivalent to other low-level wastes.

5.2.12 Analysis of "DRAFT TECHNICAL BASIS FOR SUPPORTING ADDITIONAL TECHNICAL CRITERIA AND REGULATORY GUIDES TO IMPLEMENT 10 CFR PART 61 FOR LAND BURIAL OF LOW-LEVEL WASTES"

This document provides additional guidance and technical criteria for design, operation, closure, and postoperational care of an LLW disposal facility using land burial as a disposal method. Several commenters stated that this document lacked the technical documentation necessary for classification as a technical basis. Individual commenters felt that (1) the purpose of this document needed to be clarified, and (2) the document should be incorporated in the regulations, if the technical basis can be considered requirements. One commenter stated that waste processing ought to be a function at each site and all proven methods, in addition to waste segregation and compaction, ought to be included. Another commenter stated that the relationship between the proposed regulation and other environmental laws or regulations such as the National Environmental Policy Act (NEPA) should be described. Another commenter asked how requirements for an LLW disposal site could be specified when the LLW is not defined as to volume, curies, etc.

5.2.12.1 Introduction

Several commenters felt that values for the thickness of required cover are applied to various modes of disposal without strong justification and that their empirical or experimental bases should be provided. Another commenter asked for specific values for the maximum height and allowable slope of mounded materials. This commenter felt that the passive care required by the site owner after closure should include an active monitoring program to ensure that wastes are being adequately contained.

5.2.12.2 Siting

Several commenters addressed the need for clarifying and justifying various technical concepts such as: small topographic relief; low hydraulic gradient; long residence time; devoid of surface waters; and low population areas. One commenter stated that (1) some thought should be given to site characteristics (or added barriers) which will predispose against other future uses of the site; (2) ambiguous words or unsupported numbers are less valuable than statements of how ion-exchange or retardation properties should be determined and applied; and (3) the statement on predictability of percolating ground water should be strengthened.

5.2.12.3 Design and Operations

Individual commenters felt, with regard to design and operation goals, that (1) it is a great deal more difficult to provide a positive seal above the waste than it is to provide for deflection of the bulk of infiltrated precipitation away from the waste; and (2) the need for active site maintenance by the site owner may not be eliminated since many monitoring programs encompassing a variety of functions are needed. Several commenters stated that the criterion for permeability was ambiguous and needed a technical basis. Individual commenters stated, with regard to keeping water out of buried wastes that (1) issues such as siting in humid environments need more detail; (2) any water contacting the LLW should be collected, analyzed, treated to meet effluent requirements, and released or solidified or disposed of onsite; and (3) a more specific design should be described. One commenter pointed out that there are two ways of keeping water out of buried wastes: (1) enclosing the waste in an impermeable envelope and (2) constructing the surrounding trenches such that the surrounding media has a "wick" effect to draw water away from the trench. One commenter asked for more specific details on design of trench mounds and moisture barriers. Another commenter stated that (1) the basis for specific values assigned to such things as soil permeabilities, cover thickness, thickness of sand drains should be given and (2) there is a need to show that real sites exist which can meet stated criteria (with appropriate engineering). One commenter suggested that the location of low-level waste sites should also be recorded with the appropriate register of deeds as is done with hazardous waste sites.

5.2.12.4 Waste Segregation

Most of the comments were directed to the table entitled, "Radionuclide Concentration Guidelines for Disposal by Shallow Land Burial." Individual commenters stated that the table of radionuclide concentrations (1) should be better defined--as representing average concentrations, not maxima; (2) should be correlated to the disposal techniques and required isolation times; (3) should include, if feasible, LLW containing radium and accelerator produced isotopes; (4) does not agree with the median value levels reported in an AIF/NESP study; (5) could be revised with respect to specific entries for I-129 and transuranic nuclides; and (6) may eventually be the basis of mandatory entries on all waste shipment manifests, even though many of the nuclides are either difficult to identify or are rarely present in typical wastes. Several commenters noted that the basis for these concentrations required further elaboration such as (1) specification of the total concentrations allowable at any one site at any specific time during operation, and (2) recognition that the entries in the table are dictated by predisposal operations (for short-lived isotopes) or post-closure intrusional scenarios (for long-lived isotopes) rather than by water migration. Other individual commenters stated that (1) consideration should also be given to physical form as well as chemical and radionuclide content of the waste and (2) the requirement for sufficient barriers to reclaimer intrusion should be clarified. One commenter noted that it will be extremely difficult to find suitable areas in many humid climates in order to dispose of intermediate depth burial wastes and still maintain a 3 meter clearance to ground water. Another commenter questioned the need for segregating waste in the manner prescribed.

5.2.12.5 Environmental Monitoring Program--Applicant

One commenter stated that the types of data collection recommended are all desirable, however a strong statement should be included regarding how the data will be applied as well as the guidelines on action levels. Another commenter stated that Subtitle C of the Resource Conservation and Recovery Act and rules promulgated thereto specify monitoring requirements in much greater detail than indicated here. One commenter felt that (1) collection of samples of gas emanations at the ground surface might be considered in the monitoring program; (2) the monitoring system should be installed, and baseline and background measurements collected, for at least 2 years before waste emplacement; and (3) sump water samples should be analyzed for nuclides and chemical characteristics. Individual commenters expressed concern regarding (1) the adequacy of only one continuous air monitor during waste disposal operations, and (2) monitoring after disposal during normal hours.

5.2.12.6 Monitoring--Site Owner

One commenter emphasized the need for long-term site monitoring to ensure that the site is operating as designed since the low-level waste site performance will not be known nor collective measures implemented unless the site is adequately monitored. Another commenter wondered if the NRC, EPA or the state should also have inspection rights at the site.

5.2.12.7 Site Closure and Decommissioning Plan

Individual commenters expressed the need for clarification of several aspects of the site closure and decommissioning plan regarding (1) agreements for state or federal government participation; (2) direct gamma radiation from buried wastes; (3) elimination of the potential for erosion or loss of site or LLW integrity; and (4) buffer zone requirements. One commenter requested clarification of other aspects of the plan concerning (1) custodial care by the site owner; (2) site records; (3) investigation of causes of significant increases in environmental sampling results; and (4) evaluation of present and zoned activities on adjoining areas. This commenter also expressed concern regarding (1) appropriate state input to the site closure and decommissioning plan; (2) use of state regulations in establishing acceptable levels for the rate of release of radionuclides through air, ground and surface pathways; (3) elimination of the potential for erosion or loss of site or LLW integrity; and (4) elimination of the need for active water management measures.

6. REGIONAL WORKSHOPS

During 1980 the NRC held four regional workshops in Atlanta, Chicago, Denver, and Boston that provided state officials, industry representatives, waste generators, the public, and private interest groups with an opportunity to comment on the preliminary draft regulation and other issues to be addressed and resolved. After an opening session, each workshop was usually split into two or three concurrent sessions to address institutional, organizational and technical issues. Lists of policy questions developed by NRC were made available to participants at each concurrent session to facilitate an orderly discussion. Following these discussions each session developed findings reflecting the views of participants. These findings were then reported and discussed in a final planning session. Copies of the transcripts and findings of these workshops were placed in the Public Document Room of the NRC as an official part of the record on the rulemaking procedure for Part 61.

A summary of the workshop findings is included below, followed by an analysis of the findings on specific policy questions considered at each workshop.

6.1 Summary of Findings

6.1.1 Institutional Issues

Institutional issues such as land ownership, postoperational care, institutional controls, and financing were addressed.

The workshops were generally in favor of state ownership of the low-level waste (LLW) disposal site with federal ownership preferred after site closure. It was felt that conveyance of the property from the state to the federal government upon license termination should be optional, not mandatory. In general, private ownership was not favored but approval was given to the continuing involvement of the private sector under license in the management and operations of LLW disposal facilities.

The workshops generally agreed that the licensee would be responsible for decommissioning, final site closure and stabilization, postoperational care, and corrective actions as long as it retained its license. It was felt that the licensee should maintain the site until it could demonstrate that the site required passive care only with a minimal need for ongoing maintenance by the site owner.

There were mixed views concerning how long and to what extent institutional controls can be relied upon to keep people from inadvertently intruding into the disposal site, and to monitor and assess site performance. Individual workshops felt that institutional controls can only be relied on as long as the institution exists and that no fixed number could be specified for the amount of years the site would have to be monitored after which it could be assumed to be safe. At one workshop, about half the participants thought 50 years would be a realistic expectation of government control. However, the majority at another workshop felt that an active institutional control period of 100 years and a 400-year period of passive care are sufficient to protect the public health and safety and to ensure stability of the site.

In general, the workshops felt that the proposed requirements for financial assurance were adequate, although some doubts were expressed concerning surety arrangements for decommissioning, decontamination, closure, and stabilization. Problems relating to open-ended surety requirements were recognized. It was suggested that the NRC should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement. A standard specific method of calculating costs was considered inappropriate because such costs would be site-specific.

Workshop participants recommended that the NRC develop a financial assurance system in the regulation that places full responsibility for all closure and postclosure costs with the licensee instead of the taxpayers. Some participants pointed out that none of the existing funding arrangements provide for unexpected remedial activities. These participants felt that the financial assurance mechansims proposed in 10 CFR Part 61 should ensure that the licensee be responsible for maintenance and contingency costs.

For a detailed discussion of workshop comments on financial requirements, see Appendix K.

6.1.2 Organizational Issues

Consideration was also given to organizational issues such as state participation, Federal-Agreement State relations, assistance to non-Agreement States and regional siting.

The majority of the workshops felt that the regulatory provisions for state participation should be left in general terms with it left up to the state as to when or how it wished to become involved. To achieve effective state participation, it was suggested that NRC delineate in this rule possible opportunities for state involvement to highlight to states what their rights are as they negotiate their level of participation. This would help promote state participation at a point early enough to assure that industry and NRC activities would not suddenly be confronted by a last-minute veto or state refusal to own the site because of unresolved concerns that could have been raised earlier in the decision process.

Generally the workshops agreed that it would not be desirable to mandate that Agreement States' licensure and regulatory procedures be identical to NRC procedures. On the other hand, it was felt that it was desirable to assure compliance of Agreement States with minimum federal technical standards.* One workshop suggested that implementation of environmental practices should be left up to the states. Another suggested that in order to simplify the negotiations among the states in a regional compact, Agreement States should comply with NEPA requirements.

It was generally agreed that, at a minimum, there should be federal funding and/or technical assistance to non-Agreement States to help them with organizational aspects of LLW disposal. One workshop recommended that funding and technical assistance be made available to non-Agreement States to the maximum extent possible, to be used in carrying out those investigations, studies, planning activities, regulatory activities and other project components which the state would deem necessary. Another workshop felt that it would be unfair to provide equal federal funding and technical assistance to Agreement States and non-Agreement States if the latter refused to take on regulatory responsibilities assumed by the former. Another workshop felt that the provisions for technical assistance to Agreement States should be clarified to include contract work paid for by the NRC.

One workshop felt that the appropriate geographic scope of the region of interest considered in a site-selection process should be determined by a state individually or by a group of states acting in concert in a given region.

6.1.3 Technical Issues

Technical issues that were examined included: performance objectives; de minimus levels; waste classification; nonradiological hazards; scope of regulatory guides and regulation; criteria for waste form, solidification of liquid wastes, and maximum leach rate; volume reduction; and site characterization.

*These were differences among the workshops on whether states should comply with minimum procedural requirements such as the examination of alternatives to the licensing proposal.

There were mixed views concerning specific aspects of the long-term performance objectives. Several workshops recommended that the criteria for the protection of ground water be clarified. One workshop concluded that the assumptions concerning the nature and duration of the intruder scenario should be more thoroughly explored by NRC. Overall, however, the long-term performance objectives were considered to be suitable.

There was a general agreement with the concept of having a de minimus level of activity for disposal purposes. However, there was a minority opinion at one workshop that no de minimus level should be set and that all levels should be controlled and monitored. There was general agreement at two workshops with the concept of establishing de minimus levels which are waste stream specific, thereby assuring a reasonable balance between practicality and safety. One of those workshops noted that other (nonradioactive) hazardous regulations may apply and be governing for disposal. At one workshop, it was felt that (1) de minimus levels should be established based on the critical organ dose to cover both exempt quantities and low activity, large volume, dry bulk solids; and (2) alternatives for disposing of those wastes below the de minimus level could include sanitary landfills and special sites not governed by 10 CFR 61.

There was general agreement as to the need for guidance on waste classification. There was no agreement, however, on the specifications of the waste categories. One workshop felt that maximum levels of activity for LLW disposal should be based on a design basis incident which should include reclamation of the site for residential or agricultural activity at the end of the period of institutional control. It was generally agreed that the technique for disposal should be geared to the type, form, and volume of materials to be disposed of at the site. Further, it was recommended that flexibility be built into the system so that specific cases can be accommodated. It was felt that regulatory guides are the proper place for specifying the details of a classification system.

Most of the workshops agreed that the co-siting of low-level radioactive waste and hazardous waste disposal sites should not be precluded as long as all hazards are recognized between operations at both sites. However, it was the majority opinion at one workshop to set aside the complex technical and policy issues of dealing with both low-level and hazardous wastes since too little was understood of the complexity of disposal of both types of materials at a single site. One workshop recommended that NRC investigate the possible coordination of its rulemaking with the activities of other applicable agencies.

In general, the workshops recommended that NRC adopt formal rules that establish broad performance objectives and administrative procedures, and set forth more specific program criteria and details in regulatory guides. One workshop felt that subjects for regulatory guides should include but not be limited to, site selection, disposal techniques for various types of waste (e.g., specification of engineering controls and trench operations), monitoring, packaging, site security, and site closure.

The general consensus of one of the workshops on the issues concerning requirements for waste form, solidification of liquid wastes, and maximum leach rate was that specific standards are unnecessary and may be contradictory to the performance criteria approach. It was the general opinion that the specific means of dealing with each of these issues should be left to the designer who would be guided by performance objectives.

There was a consensus at one workshop that recognition of the desirability of volume reduction should be included in the regulation, but requiring volume reduction was not considered appropriate. Another workshop concluded that some minimum acceptable standard be established but that incentives, primarily economic incentives, be the primary mechanism for achieving volume reduction.

Several workshops felt that minimum acceptable elements for site characterization should be set forth in the regulation, but the majority of these elements should be contained in regulatory guidance material as an aid in the siting process. One of these workshops felt that these minimum criteria should not result in the automatic exclusion of major sections of the country or exclude areas where identified shortcomings of a site could be rectified by engineering and site construction techniques.

6.2 Analysis of Findings on Specific Policy Questions

6.2.1 Institutional Issues

1. Who should own land used for disposal of LLW? (federal government, state government, local government, private). Why?

The workshops had extensive discussion on this issue. Comments generally favored state ownership, especially during site operation, with federal ownership preferred after site closure. Some commenters felt that private ownership should not be precluded, but in general, it was not favored.

One workshop stated that state ownership of land used for the disposal of LLW is a desirable prerequisite for licensing sites because it assures state policy input into the licensing process, and the state is more likely to be responsive to citizen concern than either a private operator or the federal government. The workshop also felt that the federal government should provide states with necessary financial and technical assistance since states may not have the technical or financial resources to solve unanticipated problems after site closure. A recommendation was made that the NRC should provide states with further legal clarification on whether state-owned and operated sites can exclude out-of-state wastes. In a minority view, the position was taken that it does not matter who owns the LLW site as long as states have the option to regulate and monitor the site.

2. What are the instances where private land ownership would be acceptable?

Most commenters saw no instances where private land ownership for commercial disposal is acceptable. Other commenters felt that private ownership of the land should not be precluded.

Most of the workshop discussions brought out that the private sector should be involved in the management and operations phase of low-level waste disposal facilities. Several commenters felt that private concerns could own or manage interim and above ground storage facilities but final disposal should only occur on government land.

3. If the land is owned by an organization other than the federal government, should there be a provision for federal government assumption of land ownership at site closure? Why or why not? Would it be useful for the states to have an amendment to federal law giving them an option to retain ownership after closure or transfer ownership to the federal government? Why or why not?

The general conclusion from the workshops was that upon license termination, federal ownership should be optional, not mandatory. The decision to convey the property to the federal government is a state option. Many commenters supported enabling legislation to permit such federal government assumption. It was suggested that such legislation should be introduced at the earliest possible time.

One workshop felt that the federal law should be amended to provide states with the option, but not the mandate, to transfer ownership of the land to the federal government at any time, at the state's decision. This workshop also noted that, since the ultimate purpose of the regulations is to protect the health and environment of the nation's citizens, there should be some form of concurrent state/federal jurisdiction over the land so that if one party fails to adequately control the site, the other party can take necessary remedial actions to protect health and environment.

4. Who should assume and carry out responsibilities for decommissioning, final site closure, and stablization? Postoperational surveillance and monitoring? Postoperational care and corrective actions? Why?

Workshop participants generally agreed that the licensee should be responsible for the facility as long as it retained its license, including decommissioning, final site closure and stablization, postoperational care, and corrective actions. In addition, workshop participants felt that the licensee should maintain the site until it can demonstrate that the site requires passive care only with a minimal need for ongoing maintenance by the site owner. However, the workshop participants felt the postoperational surveillance period should not be less than five years. A member of one workshop suggested that the regulations be changed to require postclosure observation and maintenance by the licensee for at least ten years, based on the experience of several LLW sites which indicate that problems may not arise until six or seven years after site closure.

It was concluded at several workshops that postoperational surveillance, monitoring, care and corrective actions should be the responsibility of the site owner (either federal or state government) with financial responsibility provided through the financial assurance fund collected from the operator during the operating life of the facility. One workshop summary emphasized the need for setting fees for the long-term care fund that would be adequate to cover the costs of all anticipated and unanticipated postoperational activities.

5. How long and to what extent can institutional controls be relied upon to keep people from inadvertently intruding into the disposal site; to monitor and assess site performance; and to carry out site surveillance and monitoring activities (e.g., 100 years? 200 years?). What is the rationale for the interval chosen?

In their discussion, the participants at one workshop recognized the difficulties of developing "perpetual" surveillance and maintenance for a disposal site. Participants also expressed the opinion that no "magic number" could be specified for the number of years the site would have to be monitored, after which it could be assumed to be safe.

Another workshop felt that the length of time necessary to perform monitoring and site surveillance can be determined on a technical basis. It was suggested that this should be calculated on a case-by-case basis depending on the materials disposed of onsite. The workshop concluded that institutional controls can only be relied on as long as the institution exists.

In one workshop, a majority of the group felt that an active institutional control period of 100 years and a 400-year period of passive care were sufficient to protect the public health and safety and to ensure stability of the site. A minority of the group believed that transuranics or other radionuclides, because of their long half-life, should be excluded from sites with such monitoring provisions. Some participants believed that due to the extremely low radioactivity concentration levels of such materials, the surveillance period was sufficient. Concern was voiced that there was a risk of concentrations of nuclides with unacceptable high activity, which would require more extensive site monitoring. However, the majority of the group concluded that this risk was minimal since there is a high probability that these radionuclides would be somewhat evenly distributed throughout the site, and it was believed that if such concentrations did exist, protection could be engineered prior to site closure to minimize the risk from these radionuclides.

At another workshop, about half of the participants felt that a period of 50 years would be a more realistic expectation of government control. Also, since the government cannot guarantee long-term institutional control, several participants urged NRC to strictly observe technical requirements for site selection and maintenance, thus minimizing the likelihood of unplanned remedial actions.

6. Are the proposed requirements for financial assurance adequate? What changes should be considered and why? Should there be a standard, specified method of calculating these costs? If so, what is the rationale?

In general, the workshops felt that the draft regulation's financial assurance section was adequate. However, the group cautioned against open-ended surety requirements and self-insurance. One individual felt that financial surety arrangements should be limited to cash or its equivalent. Other participants suggested that the NRC should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement.

One workshop conclusion recommended that any financial assurance arrangement should provide for remedial activities. Participants pointed out that it was naive to assume that there would not be mistakes at an LLW site, and that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for unexpected remedial work. Participants also discussed the importance of providing a fund to cover unpredictable contingencies beyond the control of the operator, the state, or the federal government. Some people commented that a portion of the financial assurance funds from all low-level waste facilities could be pooled into one national contingency based on the assumption fund. Such a financial assurance mechansim is based on the assumption that the odds are against all sites experiencing unexpected and costly remedial programs, thereby creating a pool of funds to help pay the costs of these sites that do experience unanticipated costs. The tax consequences of such an approach were also discussed.

One workshop summary concluded that a standard, specific method of calculating costs was inappropriate, because such costs would be site-specific. However, participants recognized the importance of incorporating inflation into the total costs of closure and postclosure care. One person suggested that the government periodically examine the long-term care fund and surety arrangement so that the funds could be revised to keep pace with changes in inflation.

6.2.2 Other Institutional Issues

Several additional issues were addressed at workshops concerning license transferability, disposition of naturally occurring and accelerator produced radionuclides, and regional siting. Participants concluded that if a private operator buys out the private concern which is operating a low-level waste facility, the license to operate the facility should not be transferrable. Regulatory decisions by NRC and EPA over naturally occurring and accelerator produced radionuclides were requested. Participants also expressed support for siting low-level waste facilities on a regional basis. One participant noted that states generating large amounts of low-level waste should consider development of regional sites as they will be technically better prepared to serve in this capacity.

At another workshop, additional discussion was focused on postoperational use of land, the definition of LLW, and the siting of LLW disposal facilities. The participants concluded that it was not clear what, if any, uses of land used for LLW disposal were acceptable after site closure. They requested that NRC provide a more explicit definition of LLW and also develop a straightforward waste classification system. Several participants suggested that the integrity of the geologic medium in which the LLW is buried, and not the depth of the LLW burial, should be used as an indication of how well the possibility of human exposure is minimized.

6.2.3 Organizational Issues

1. Should the provisions for state participation be left in general terms, or should they be refined to specify how and when states should be involved? How can states most effectively participate in the licensing process including development of environmental impact statements and other analyses and assessments? Should states be required to participate? If not, how can they best be encouraged to participate early in the process? Should they be so encouraged? How can NRC minimize the likelihood that a state might enter the process in its final stages, possibly bringing disruption and delay?

The majority of the people attending workshops felt that the provisions for state participation should be left in general terms, with the state being able to determine when and how it wished to become involved. People at one workshop suggested that the provisions for public participation in a state should not be left in broad terms but should specify how and when states, local governments, citizen groups and other public participants should be involved. The participants in this workshop also felt that this participation should generally be limited to a notice and an opportunity to be heard.

Participants at two workshops suggested that the first step for a state involved in the siting process would be to determine if establishment of a site within its boundaries would be a public convenience and necessity. They argued that this finding would have to be made before a state could proceed to determine the technical merits of a site.

The written summary of one workshop generally agreed that most states would probably want to be involved in the siting process from the front end, perhaps even determining potential sites before the industry had proposed a particular site. The findings also pointed out the disadvantages with such an action, i.e., such a well-prepared state would probably be more likely to be chosen as a recipient state because it has already proposed the background work. Workshop participants also acknowledged that a state should participate at an early enough point to assure that industry and NRC activities would not suddenly be mooted by a last-minute state refusal to own a site due to unresolved state concerns that could have been raised earlier.

Participants at another workshop supported the notice requirement embodied in the notice of intent provisions of Section 61.26(b) in the preliminary draft of Part 61. They also felt that the applicant should demonstrate in his license application that the state does not object to the licensing process going forward. This requirement was vaguely akin to the requirement to obtain a certificate of public convenience and necessity from a state power commission prior to the NRC considering an application for a construction permit for a nuclear reactor. They believed that there should be no requirement that the applicant obtain final state approval prior to the license application. Although it was believed that it should be a state option to participate in the licensing process, minimal notice provisions would permit the state the opportunity to be involved at the earliest stages of the proceedings.

This workshop also recommended that the regulation should require that the state consult with local citizens as a precondition for approval of any state plan of participation. The majority at this workshop believed that the appeal process from the denial of a state plan of participation should be specifially articulated. The Commission was encouraged to adopt a simple and speedy appeal process, with the state specifically guaranteed the right to participate at any stage after receipt of notice of intent, whether or not funding is sought from the Commission. This workshop also felt that Section 61.48(b)(1) should be clarified. The phrase which now reads "The proposed activities are authorized by law..." should be changed to read "The proposed activities are authorized by Federal law..."

Another workshop liked the provision under which a state has the opportunity to propose its own format for participation which would then be negotiated with NRC. However, the workshop concluded that to achieve effective state participation, it is essential that NRC fully delineate in this rule possible opportunities, throughout the regulatory critical path from the filing of the notice of intent through to closure and license termination, for state involvement and input. This list of opportunities, which need not be exhaustive, would serve to highlight to states what their rights are as they negotiate their level of participation with NRC.

This workshop felt that non-Agreement States should not be required by NRC to participate in the siting and licensing of an LLW facility. It felt strongly, however, that NRC should invite and encourage state participation beginning with the filing by an applicant of the notice of intent. In order to implement this suggestion, it recommended that NRC add to the proposed rule the following:

- That an applicant be required to file with the state and local community a copy of his notice of intent.

- That NRC, upon receipt of a notice of intent, officially notify in writing the governor, the state, NRC liaison officers, the legislature and other appropriate officials of the impending application. At this time, NRC would also be required to invite and encourage the states' participation.

This workshop also agreed that the best means of protecting the states' rights is the existing regulatory requirement of state ownership of land used for an LLW disposal facility. The workshop recognized the potential problem of federal purchase of a candidate site which is rejected by the state on findings of fact after prelicensing regulatory procedures are completed.

Another workshop felt that the draft regulation should state explicitly the limits of authority that can be delegated by NRC to non-Agreement States pursuant to a state's proposal for participation and that these legal and constitutional limitations should be included in the general provisions. It also concluded that the proposed regulation should allow the applicant adequate notice of the nature and extent of state and local participation. Before the onset of formal NRC licensing proceedings, there should be a reasonable specified interval between the filing of the application and the payment of the application fee to allow state governments to propose, and NRC to accept their plans for participation. After reviewing state participation plans, the applicant should be able to withdraw its application and fee without prejudice.

2. Are the provisions for technical assistance to Agreement States adequate? What changes should be considered?

One of the workshops felt that to avoid confusion any reference to assistance to Agreement States or statutory mandates be removed and incorporated in the part of 10 CFR which relates to Agreement States. It also stated that the NRC should ensure that Agreement and non-Agreement States should be treated equally as a general policy matter.

Another workshop questioned what was meant by "technical assistance." It felt that the draft regulation should explicitly define the term "technical assistance." In particular, it thought the term should include contract work paid for by the NRC.

3. Should NRC have a statutory mandate to require uniformity in the regulations and procedures used by NRC and the Agreement States in licensing LLW disposal sites? Why or why not? Should Agreement States have to assure compliance with minimum federal standards? Should they adopt standard environmental review procedures? Why or why not?

One workshop agreed that there should be minimum technical standards for the disposal of LLW that would apply to Agreement and non-Agreement States. However, it noted that a statutory change might be required to mandate compliance by Agreement States with minimum federal technical standards. The workshop also agreed that it would not be desirable to mandate that Agreement States' licensure and regulatory procedures be identical to NRC procedures; Agreement States, with a transfer of licensing and regulatory authority from NRC, should have the right to develop their own regulatory and licensing procedures.

This workshop extensively discussed the potential problems that could occur because Agreement States are not required to comply with NRC siting and licensing procedures for LLW disposal facilities. There was concern that Agreement States are not required, absent a statutory change, to conduct a full NEPA investigation as NRC is required to perform. Specifically, there was concern that an alternative site analysis would not be performed. This was identified as a particular problem in the siting of an LLW disposal facility within the context of a regional state compact or other regional grouping of states. Differences, not only between Agreement States and NRC non-Agreement State procedures, but also among different Agreement States within the same region, pose even further problems. Participants recognized, therefore, that minimum procedural as well as technical standards may be beneficial, Although this would require statutory change. This workshop emphasized that to the extent possible, maximum flexibility and authority should be preserved for the Agreement States to develop procedures that best meet their unique requirements and needs.

Another workshop concluded that minimum technical licensing standards should be required but licensing procedures should be left up to the state. Participants noted that uniform procedural standards would essentially negate the benefits of Agreement State status. The workshop felt that environmental practices should also be considered, but their implementation should be left up to the states. Participants recommended against requiring state environmental practices to be "equivalent to" federal minimum practices, since this would add another element of dispute and subjectivity. In addition, the workshop felt that the format for the license application should be standard.

Another workshop felt that the regulation should be clear on what NRC will require of the applicant in an environmental assessment. It also suggested that the regulation should be tempered to provide equity to both Agreement States and non-Agreement States to prevent forum shopping by advocates.

4. Should there be federal funding and/or technical assistance to non-Agreement States to help them with the organizational and institutional aspects of LLW disposal, including participation in the NRC licensing process and the development of plans for site closure, stabilization, and/or postoperational monitoring? Why or why not? Should states have federal funding and/or technical assistance for activities related to the development of additional disposal capacity, such as site selection? Why or why not?

At one workshop, representatives of Agreement States were very outspoken in their opinion that federal funding and technical assistance should be made available to Agreement States, since by their very status these states have agreed to take on the regulatory responsiblities over LLW sites. For the same reason, some state participants believed it would be unfair to provide similar aid to non-Agreement States if they have refused to formally take on such regulatory responsibility. While federal funding was considered necessary, the group recognized that by accepting such funds, a state would become beholden to the federal government, thereby losing some of its independent control over an LLW project. Some participants suggested that one method of minimizing this threat would be to have federal funding made available to the state before a specific site has been selected. This would afford the state greater latitude to assess the characteristics of either the entire state or of several potential sites which may be suggested by industry.

Another workshop felt that the regulation cannot provide incentives which appear to promote siting, but, at the same time, it should not discourage state initiative.

The consensus at another workshop was that, at a minimum, there should be federal funding and/or technical assistance to non-Agreement States to help them with organizational aspects of LLW disposal.

One workshop strongly recommended to NRC that funding and technical assistance be made available to non-Agreement States to the maximum extent possible. These funds would be used to carry out those investigations, studies, planning activities, regulatory activities and other project components which the state would deem necessary. This workshop also recommended that:

- o NRC delete the phrase, "Subject to the availability of funds" from Subpart C, Section 61.48, paragraph (b).

- o NRC provide an appeal procedure to a state which believes that insufficient funding or technical assistance are being provided.

- o NRC include language in this rule expressing its intent to make every effort to fund fully all requests deemed essential by the state. The workshop felt that the best hope for siting an LLW facility lies in achieving fullest and earliest state cooperation and that this can best be achieved by removing the financial burden from the states.

5. What is the appropriate geographic scope of the "region of interest" to be considered in a site selection process?

One workshop concluded that the appropriate geographic scope of the "region of interest" should be determined by a state individually or as a group of states acting in concert in a given region. The group felt that the technical analysis of whether an applicant has sufficiently considered alternatives should be left to the Commission.

In another workshop, the conclusion was that in considering the scope of the "region of interest" for selecting an LLW site, the economics of the site would have to be taken into account; i.e., a sufficient amount of waste would have to be generated in the region to meet the economies of scale to make the facility economically viable.

6.2.4 <u>Other Organizational Issues</u>

Several additional issues were addressed at one workshop concerning extent of NRC legal authority, coordination of rulemaking, and scope of access of waste. It was felt that the regulation should clarify, in the general provisions, the extent of the legal authority that NRC has to regulate low-level waste facilities. The workshop also felt that the NRC should coordinate its rulemaking with the activities of other responsible agencies including DOE, SPC, EPA, DOT, and USGS. It suggested in this regard that low-level waste regulations should anticipate compatibility and colocation possibilities with other federal statutes and regulations governing the disposal of hazardous material. Another recommendation by the workshop was that the regulations should provide for a determination of the scope of access and should prevent a state (or other owning or operating authority) from arbitrarily closing or restricting access. The workshop felt that procedures for expanding, restricting, or eliminating access or type of waste accepted should be developed and included in the regulations.

Another workshop addressed additional issues concerning record keeping and local community participation in the regulatory process. The workshop recommended to NRC that full records regarding the type of materials, their composition, and their location within the site; the volumes of material by type; the identity of the shipper and the materials to be shipped; and where they are located or filed, in all cases, within the state after closure. This workshop also recommended that the NRC include in this rule general provisions for local community participation in the regulatory process. It felt that these arrangements could be worked out between the state and the local community.

6.2.5 Technical Issues

1. What are the appropriate performance objectives for the LLW disposal rulemaking? Are any of the objectives now in the draft unnecessary? Why?

In general, the long-term performance objectives were considered to be suitable. However, there were some mixed views concerning specific standards proposed for levels of contamination at the site boundary and for the time after controls are removed.

Several workshops recommended that the criteria for protection of ground water be clarified. At one workshop, it was concluded that relevant EPA standards should be used and that EPA should complete, as soon as possible, its standards for low-level radioactive waste sites. At another workshop, the group was evenly divided between those who supported a requirement that the EPA standards be met at the site boundary and those who supported the requirement that the EPA standards be met at feasible sources of drinking water. There was a consensus that the regulation should be written to specify that the requirement should be met continuously. Another workshop recommended that NRC should consider establishing two ground-water contaminant criteria for the site boundary: (1) for design purposes, a calculated contaminant level using National Primary Drinking Water Standards and (2) for compliance during active site operation, and for the period following site closure until active institutional controls are not required, a readily measurable contaminant level (in pico-curies/liter).

There was considerable discussion at one workshop of the contaminant level allowed for the intruder after 100 years of active control. It was argued that a 25 mrem/yr standard should be used instead of a proposed 500 mrem/yr standard since the intruder, such as a householder, could be in constant rather than intermittent contact. At issue was the reliability of passive controls such that any intruder would be an episodic event. The issue was not resolved and it was concluded that the assumptions concerning the nature and duration of the intruder scenario should be more thoroughly explored by NRC.

2. What de minimus level is appropriate? Where and how should this level be set, and what is the rationale for setting it there? Should NRC establish de minimus levels for LLW below which NRC would not regulate disposal?

There was a general agreement with the concept of having a de minimus level of activity for disposal purposes. However, there was a minority opinion at one workshop that no de minimus level should be set and that all levels should be controlled and monitored. Several workshops addressed the issue of how low de minimus should be. At one workshop it was felt that (1) de minimus levels should be established based on the critical organ dose to cover both exempt quantities and low activity, large volume, dry bulk solids; and (2) alternatives for disposing of those wastes below the de minimus level could include sanitary landfills and special sites not governed by 10 CFR 61 (possible onsite with a shallow earth cover). At two workshops there was general agreement with the concept of establishing de minimus levels which are waste stream specific, thereby assuring a reasonable balance between practicality and safety. One of these workshops noted that other (nonradioactive) hazardous regulations may apply and be governing for disposal.

Two important policy related issues were raised but not conclusively resolved at one workshop. One issue was the preemption of NRC standards over state and/or local standards, in non-Agreement States. The other issue was the equal treatment of all generators with respect to de minimus levels. Specifically, there was a question as to whether the de minimus levels would be directed primarily to benefit the medical community and that industrial generators, especially power plants, would be effectively excluded.

3. How should guidance on the kinds of wastes that should be disposed of in certain types of facilities be implemented by rulemaking? To what extent should NRC consider potential future intrusion and reclamation in developing this guidance?

At two workshops, participants recommended that NRC establish concentration limits or ranges which would be acceptable for a low-level waste land disposal; that these ranges be used to adjust for site-specific conditions; that NRC attempt to give guidance as to which waste streams would be considered for each category of disposal; that flexibility must be built into the system so that specific cases can be accommodated. One of these workshops also recommended that NRC consider impacts of different waste streams and different institutional controls as may be required.

At the other workshop there was no agreement on the specifications of the waste categories. Some parties favored classification by isotope, others by more general categories, and others favored no classification within LLW. All parties recognized the need for greater quality control and compliance with the classification system finally adopted. Participants urged NRC to recognize the potential adverse economic incentive which may arise in a classification system whereby the generator may be inclined to misclassify his waste to permit less costly disposal techniques. It was also concluded that regulatory guides are the proper place for specifying the details of a classification system.

At a third workshop, there was unusual agreement that the concept of a maximum level was necessary to allow design criteria to be met. The consensus was that these levels should be based on a design basis incident which should include reclamation of the site for residential or agricultural activity at the end of the period of institutional control. The viewpoint was expressed that the present allowed levels of transuranics not be increased.

At a fourth workshop, there was general agreement with regard to disposal techniques that site design and layout, trench depth, burial depth, waste containers, etc. all should be selected with the specific waste types and forms to be disposed of, the specific activity and overall planned site capacity and separation in mind. In other words, the technique should be geared to the materials--type, form, and volume--to be disposed of at the site. It was also pointed out that there was nothing in the regulation which would create a necessity for multiple sites, even if multiple techniques were necessary.

4. What considerations of nonradiological hazards in LLW disposal are appropriate in rulemaking? How would this provision of the rulemaking relate to other federal rulemakings for nonradiological hazardous wastes? Should there be joint siting of hazardous and LLW facilities?

Most of the workshops agreed that the co-siting of low-level radioactive waste and hazardous waste disposal sites should not be precluded so long as all hazards are recognized between operations at both sites. However, at one workshop it was the majority opinion to set aside the complex technical and policy issues of dealing with both low-level and hazardous wastes since too little was understood of the complexity of disposal of both types of materials at a single site.

One workshop felt that (1) LLW sites should not accept appreciable quantities of hazardous waste and in no case should an LLW site accept hazardous waste which would compromise the integrity of the site; and (2) hazardous waste sites should accept such waste which is minimally contaminated with radioactive material. Another workshop concurred with the concept of inerting any nonradiological hazard which would adversely affect the radiological safety of the site.

At another workshop the consensus was reached that 10 CFR 61 should not prohibit the licensing of an LLW site adjacent to a hazardous chemical disposal site (or vice versa), but that if colocation of such sites is proposed, the license application should be required to show that possible synergistic effects have been considered in preparing the license application. A consensus was also reached that the regulations (10 CFR 61) should be modified to include those components of the hazardous waste regulations that apply to the chemicals and biological material associated with radioactive waste (i.e., scintillation vials, pathogenic materials). This could be accomplished by including any special requirements in 10 CFR 61, or by reference to the fact that the site must meet the appropriate sections of the EPA's regulations on hazardous waste disposal sites.

One workshop felt that NRC should closely coordinate with other federal agencies regarding definition of radioactive waste. Another workshop took a similar view recommending that NRC investigate the possible coordination of its rulemaking with the activities of other applicable agencies, including DOE, EPA, DOT and DOI regarding: (1) definition of radiological waste, including limits; and (2) siting of combined chemical and radioactive waste operations as provided under co-siting.

5. In what areas should NRC provide specific guidance in the form of regulatory guides for LLW? What level of specificity in the requirements should be incorporated in the regulation, and what level of specificity should be incorporated in the guidance, if any?

The general feeling at one of the workshops was that the regulations, as written, are too specific in many instances. It was felt that the performance criteria should be relied upon to set the basic standard, while specific system elements should be designed with the maximum of flexibility to achieve the performance criteria for a particular site and a given variety of waste types. Regulatory guides were seen as useful additions to the regulation, but only to the extent that the NRC did not treat these guide documents as criteria or specifications to be met.

There was a general consensus at another workshop that the regulation should contain (1) specific references to adopted standards where they exist (i.e., for noxious gases); (2) a list of design considerations where specific numerical values cannot be established--the burden should be placed on the license applicant to show how these issues were considered and evaluated; and (3) a general tightening of the definitions--in many cases definitions would be contained in regulatory guides rather than in the regulation.

Another workshop recommended that NRC adopt formal rules that establish broad performance objectives and administrative procedures, and set forth more specific program criteria and details in a regulatory guide, to be published as a program supplement to the rules. This workshop felt that subjects for regulatory guides should include but not be limited to site selection, disposal techniques for various types of waste (e.g., specification of engineering controls and trench operations), monitoring, packaging, site security, and site closure. Similarly, another workshop recommended that NRC regulatory guides should be developed and should specify the depth of detail expected in procedures and other submissions. This workshop felt that these guides should also recognize the presence and provide guidance for the disposal of naturally occurring radioactive material, such as radium, at the low-level waste disposal facility.

6. Are the criteria for the waste form appropriate? What criteria should be added, and why? What should be deleted, and why?

7. How inclusive should the requirements for solidification of liquid wastes be? Should there be exemptions for small generators? Why or why not? If so, how should such exemptions be provided?

8. Should a maximum leach rate requirement be established in the rulemaking? Why or why not?

The general consensus of one of the workshops on each of these issues was that specific standards are unnecessary and may be contradictory to the performance criteria approach. It was the general opinion that the specific means of dealing with the issue--form, for example--should be be left to the designer who would be guided by performance objectives. This reflected the majority opinion that the performance of the overall system, and not a given single component, was the important issue. Thus in the case of waste form, it was seen that both form and packaging should be treated together in assessing site stability, stability being the primary issue. Performance criteria for site stability should be established, leaving the specifics of form, packaging, etc. to the designer. This same opinion emerged with regard to the issues of solidification of liquid and resin wastes, and soil characteristics.

At another workshop it was recognized that it is desirable to regulate the level of radioactivity at the site boundary and that a systems approach will determine the level of radioactivity in the waste, the containers to be used, the geological medium, and the distance from the burial point to the site boundary--in addition to the leach rate--that will ensure compliance with the regulatory limit at the site boundary.

At another workshop participants recommended that the proposed rules strive for uniformity in LLW site operations, provided that states may exercise their congressionally-mandated prerogatives to require more stringent standards.

9. Should there be a minimum requirement for volume reduction? Why or why not? If such reduction should be required, to what extent should it be required?

There was a general consensus at one workshop that incentives, primarily economic incentives, would be sufficient to cause the appropriate volume reduction. It was pointed out that some generators may not be as motivated as others to respond to such incentives and that their lack of motivation affected other site users. It was concluded, therefore, that some minimum acceptable standard be established but that incentives be the primary mechanism for achieving the volume reduction.

There was a consensus at another workshop that recognition of the desirability of volume reduction should be included in the regulation. However, including volume reduction as a requirement was not considered appropriate. One suggestion was that the possibility of volume reduction should be one of the design considerations included in the review of license applications. This would assist the generator and the disposal site operator to justify the capital cost of compactors, incinerators, and other volume reduction equipment.

10. Should specific elements of site characterization be set forth in the regulation? In the guidance? Why or why not?

At one of the workshops it was felt that minimum acceptable elements should be set forth in the regulation, but the majority of the site elements for characterization should be contained in regulatory guidance material as an aid in the siting process. Again, consistent with the general objective of maximizing flexibility, this approach was seen as giving the designer the latitude to explore and describe the site in the context of its uniqueness. It was felt that basic standards are, however, necessary.

Another workshop recommended criteria constraining site selection. It felt that NRC should establish, in a general form in the regulations and in a specific form in the regulatory guides, minimum geological, hydrological, etc. criteria which would exclude an area from consideration as an LLW site. These minimum criteria should not result in the automatic exclusion of major sections of the country or exclude areas where identified shortcomings of a site could be rectified by engineering and site construction techniques. The workshop also recommended that (1) NRC should examine, in its regulatory guides, those site constraints which could be overcome by specified engineering or construction techniques; and (2) NRC should specify in the regulatory guides site-specific information required in an application, such as the maximum leach rate.

6.2.6 Other Technical Issues

Several additional issues were addressed at the workshops. These issues were site selection process, inventory of radionuclides, site suitability and buffer zone requirements.

One workshop recommended that an applicant can nominate a site for LLW disposal but such a site cannot be considered by NRC in an application unless: (1) a general area reconnaissance survey to determine possible site alternatives, has been performed by the state and/or DOE in coordination, if applicable, with any appropriate federal land manager; and (2) a joint federal-state environmental analysis has been prepared that would include an extensive geologic survey funded by DOE for each site.

Another workshop recommended that a federal centralized data bank be established to contain information on the inventory of radionuclides, chemical form, and the most toxic material in the waste for each low-level waste disposal site.

At another workshop, participants recommended that NRC redraft 61.96d(8) recognizing that some of the lesser severe problems may be engineered out; or that the features listed in 61.96d(8) be reorganized in view of their contribution to low-level waste migration from the facility. The participants also recommended that NRC needs to provide more detailed guidance on requirements for the buffer zone around the low-level waste disposal facility.

LIST OF COMMENTERS ON NOTICE OF DEVELOPMENT OF A RADIOACTIVE WASTE DISPOSAL CLASSIFICATION SYSTEM

43 FR 36722 (8/18/78)

1. ACRS Subcommittee on Waste Management
2. Cornell University
3. Portland General Electric Company
4. ICN Chemical and Radioisotope Division
5. U.S. Geological Survey
6. Pennsylvania Department of Environmental Resources
7. U.S. Bureau of Reclamation
8. U.S. Environmental Protection Agency
9. Utility Waste Management Group
10. Massachusetts Energy Facilities Siting Council
11. Department of Energy Richland Operations Office
12. California Department of Health Services
13. Nuclear Engineering Company, Inc.
14. Department of Energy Office of Nuclear Waste Management
15. Technical Advisory Panel
16. David L. Schreiber
17. James M. Byrne

LIST OF COMMENTERS ON ADVANCE NOTICE OF PROPOSED RULEMAKING ON LLW DISPOSAL REGULATION (10 CFR Part 61)

43 FR 49811 (10/25/78)

1. Wells Eddleman
2. Bureau of Land Management
3. Connecticut Department of Environmental Protection
4. Portland General Electric Company
5. Armadillo Coalition of Texas
6. California Department of Health
7. Pennsylvania Dept. of Environmental Resources
8. Donald B. Stal
9. Center for Law and Social Policy
10. Utility Waste Management Group
11. Louise Gorenflo
12. Environmental Policy Institute
13. Stark County (Illinois) Zoning and Planning
14. Exxon Nuclear Company
15. Township of Lower Alloways Creek
16. Six Power and Utility Companies
17. Toulon (Illinois) United Methodist Church
18. Texas Department of Health
19. Consolidated Edison Company of New York
20. Kentucky Department for Human Resources
21. Yankee Atomic Electric Company
22. Commonwealth Edison
23. Natural Resources Defense Council, Inc.

24. U.S. Environmental Protection Agency

25. Ohio Environmental Protection Agency

26. Chem-Nuclear Systems, Inc.

27. Westinghouse Electric Corporation

28. Tennessee Valley Authority

29. Ohio Department of Health

30. New York Department of Environmental Conservation

31. Pennsylvania State University

32. HYRE Enterprises, Inc.

33. Atomic Industrial Forum, Inc.

34. Conference of Radiation Control Program Directors, Inc.

LIST OF COMMENTERS ON PRELIMINARY DRAFT REGULATION

10 CFR Part 61 (11/5/79) - 45 FR 13104 (2/28/80)

1. Nevada Division of Health
2. Florida Department of Environmental Regulation
3. Department of Energy, Division of Waste Products
4. Nuclear Safety Associates
5. Natural Resources Defense Council
6. California Energy Resources Conservation and Development Commission
7. West Virginia Geological and Economic Survey
8. Kansas Department of Health and Environment
9. U.S. Geological Survey
10. Tennessee Valley Authority
11. Penberthy Electromelt International, Inc.
12. Travenol Laboratories
13. Arkansas Power & Light Company
14. Duke Power Company
15. North Carolina State University
16. United States Steel Corporation - Texas Uranium Operations
17. Pennsylvania Power & Light Company
18. American Hospital Association
19. Ford, Bacon & Davis Utah, Inc.
20. Department of Energy - Clinch River Breeder Reactor Plant Project Office
21. Atomic Industrial Forum/Utility Nuclear Waste Management Group
22. Consumers Power Company
23. Los Alamos Scientific Laboratory (University of California)
24. Pharmaceutical Manufacturers Association

25. Chem-Nuclear Systems, Inc.
26. Yale University
27. Ralston Purina Company
28. Illinois Department of Public Health
29. Wisconsin Division of Emergency Government
30. Vermont Legislative Council
31. Connecticut Department of Business Regulation
32. U.S. Ecology, Inc.
33. Marvin I. Lewis

Appendix D

LOW-LEVEL WASTE SOURCES AND PROCESSING OPTIONS

This appendix presents a data base on sources of low-level radioactive waste (LLW), in addition to a number of options for processing this waste. The data base includes estimates of:

- the physical, chemical, and radiological characteristics of LLW projected to be routinely generated during the period from 1980 to the year 2000;

- the changes in these characteristics under a number of viable waste treatment technology options;

- the costs for these waste treatment options based upon currently available technology; and

- data on occupational exposures and environmental releases associated with the waste treatment options.

These characteristics are utilized to determine the performance and technical requirements for acceptable disposal of the wastes, and to determine the environmental impacts of selected disposal alternatives.

Section 1 is an introduction to the appendix and provides a background rationale for the assumptions used in developing the data base. Section 2 describes the waste sources (streams) that will be considered and Section 3 presents the characteristics (including volumes and radioactivity concentrations) of these waste streams prior to waste treatment. This section is followed by Section 4, which very briefly discusses various types of waste processing and treatment options which can be applied to these streams, and selects some specific representative treatment options for further consideration. Section 4 also quantifies several impact measures (occupational exposures, population exposures, costs, and energy use) associated with the selected waste treatment options. Section 5 presents the characteristics of the waste streams after application of the selected waste treatment options. Finally, Section 6 describes some potential waste streams that may be generated in the future, for which projections of waste quantities potentially produced to the year 2000 are considered to be speculative.

1. INTRODUCTION AND BACKGROUND

There are many facilities and diverse processes that generate radioactive waste, ranging from nuclear fuel cycle facilities to medical institutions and industrial facilities. To determine the environmental impacts of disposing of these wastes, their physical, chemical and radiological characteristics are estimated and projected on a regional basis over a time period from 1980 to the year 2000. The radioactive wastes projected in this appendix are then assumed to be disposed into a reference near-surface disposal facility that is typical of existing disposal facilities. (See Appendix E for a description of the reference disposal facility.) This provides a base case against which potential alternatives for waste form and disposal facility design and operation can be analyzed.

The regions considered as part of developing the waste projections are shown in Figure D.1. The five regions range in number from 7 to 14 states each, and correspond to the five NRC regions. Each region could represent a large multistate compact formed for waste disposal.

Projecting regional waste generation to the year 2000 results in an upperbound volume of waste produced during this period of about one million cubic meters (about 35 million ft^3) of waste per region, sufficient to fill a single disposal facility of up to a few hundred acres in size using existing trench disposal practices. Existing commercial disposal facilities range from twenty to a few hundred acres in size. A million cubic meters of waste corresponds to an average of 50,000 m^3 (1.77 million ft^3) of waste disposed per year over a period of 20 years, or about 4167 m^3 (147,000 ft^3) a month. By comparison, the current limitation on monthly receipt at the Barnwell, S.C. disposal site is 200,000 ft^3 per month and this limit will be reduced to 100,000 ft^3/month by October 1981 (Ref. 1).

Within the last few years, a considerable amount of data has been generated on the characteristics of radioactive waste streams. Even so, in some cases the data is rather limited and simplifying assumptions are made as a result. The waste projections are also limited by the inherent variable nature of waste generation. Facilities producing waste may expand, reduce or otherwise modify operations, depending upon governmental, social, or economic influences that are not readily predictable. Future development in waste treatment processes is also expected to alter the characteristics of the waste streams that are produced, as are regulatory requirements and actions.

Given the inherent uncertainties in waste projections over the next twenty years and beyond, NRC staff have concentrated on wastes that are either presently being routinely generated, or are expected within the next few years to be produced in significant quantities. These include wastes from the present once-through uranium fuel cycle, institutional wastes, and radioisotope industrial wastes. There are also a number of other waste streams that may be produced in the future--e.g., wastes produced from recycle of uranium fuel--but the timing for their generation, their production rates, and their characteristics are speculative at this time. These streams are discussed in Section 6 in lesser detail. In any case, new waste streams will be continuously generated as processes change, new facilities are built, and so forth.

Development of the data base has been divided into three components: (1) the characteristics of "untreated" LLW, (2) the waste treatment systems which can be utilized and their potential effects on LLW, characteristics and (3) alternative LLW characteristics under several of these waste treatment options. The waste sources have been subdivided into a number of individual streams, each of which differ significantly in characteristics and generation sources. The

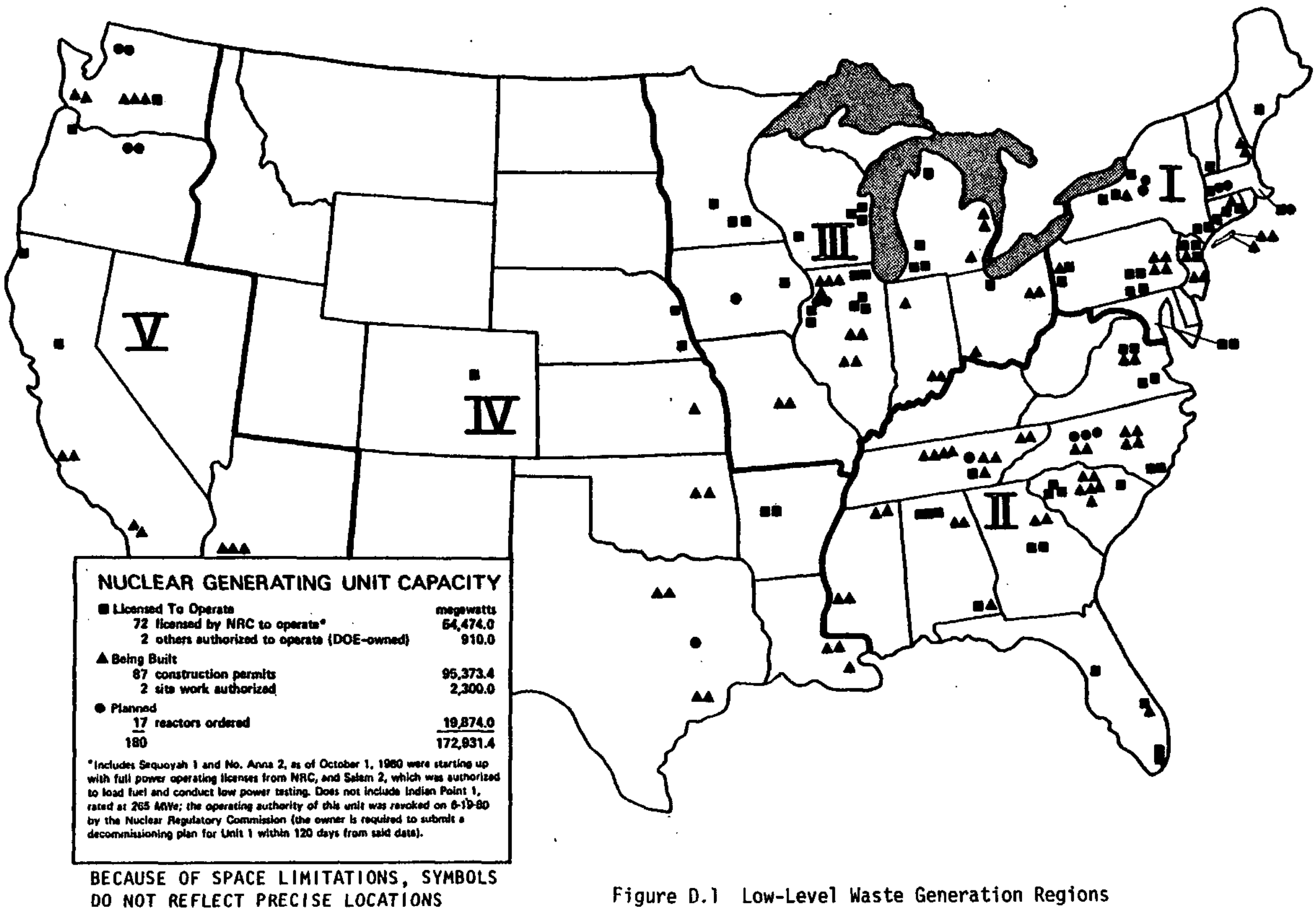


Figure D.1 Low-Level Waste Generation Regions individual waste streams are then regrouped into 4 groups which are distinguished by the macroscopic properties of the wastes. All of these streams are presently being generated and shipped to waste disposal sites or have a reasonably high possibility of being generated by the year 2000.

The detailed breakdown enables (1) rapid and flexible calculation of impacts, (2) incorporation of future waste treatment technologies, (3) a rapid increase in the number of streams considered, and (4) improvements in the accuracy of information in a given stream. It is expected that much additional data on waste characteristics will be acquired over the next few years. Additional waste streams may also be identified. Therefore, the structure of the data base on waste characteristics has been designed to be flexible to incorporate new data in a straightforward manner.

2. WASTE STREAM DESCRIPTIONS

This section provides a description of the waste streams that are presently being routinely generated or are expected to be routinely generated in significant quantities in the relatively near future. Section 2.1 is an overview of current waste generators, which comprise nuclear fuel cycle waste generators and nonnuclear fuel cycle waste generators. Sections 2.2 through 2.5 then provide a more detailed discussion of the waste streams produced by these waste generators. In this appendix, 25 distinct waste streams have been identified and these are summarized in Table D.1.

As shown in the Table, the 25 waste streams may be grouped into the following five major waste sources, which include three generic fuel cycle sources and two generic nonfuel cycle sources:

- Nuclear fuel cycle
  - Central station nuclear power plants
  - Fuel fabrication plants
  - Uranium hexafluoride (UF_6) conversion plants
- Nonnuclear fuel cycle
  - Institutional facilities
  - Industrial facilities

2.1 Overview of Waste Generators

Nuclear Fuel Cycle Facility

Nuclear fuel cycle waste generators include facilities involved in the commercial generation of electrical power through the use of nuclear energy. The current fuel cycle is based upon once-through use of uranium fuel as shown in Figure D.2 (Ref. 2).

The nuclear fuel cycle begins with mining and milling of uranium ore. Uranium ore is generally obtained from either open pit or underground mines and is usually shifted to a centralized mill for processing. Uranium mills convert uranium ore to yellowcake, which primarily consists of U_3O_8. Disposal of

Table D.1 Waste Sources and Streams

Nuclear Fuel Cycle	Abbreviation
Central Station Nuclear Power Plants	
Ion Exchange Resins	IXRESIN
Concentrated Liquids	CONCLIQ
Filter Sludges	FSLUDGE
Cartridge Filters	FCARTRG
Compactible Trash	COTRASH
Noncompactible Trash	NCTRASH
Nonfuel Reactor Core Components	NFRCOMP
Decontamination Resins	DECONRS
Fuel Fabrication Facilities	
Process Wastes	PROCESS
Compactible Trash	COTRASH
Noncompactible Trash	NCTRASH
Uranium Hexafluoride Plants Process Wastes	PROCESS
Nonfuel Cycle	
Institutional Facilities	
Liquid Scintillation Vials	LIQSCVL
Absorbed Liquid Waste	ABSLIQD
Biowaste	BIOWAST
Trash	COTRASH
Industrial Facilities	
Waste from Isotope Production Facilities	ISOPROD
High Activity Waste	HIGHACT
Tritium Production Products Manufacturing Waste	TRITIUM
Sealed Sources	SOURCES
Accelerator Targets	TARGETS
Source and Special Nuclear Material Waste	SSWASTE
Source and Special Nuclear Material Trash	SSTRASH
Low Activity Waste from Various Sources	LOWASTE
Low Activity Trash from Various Sources	LOTRASH

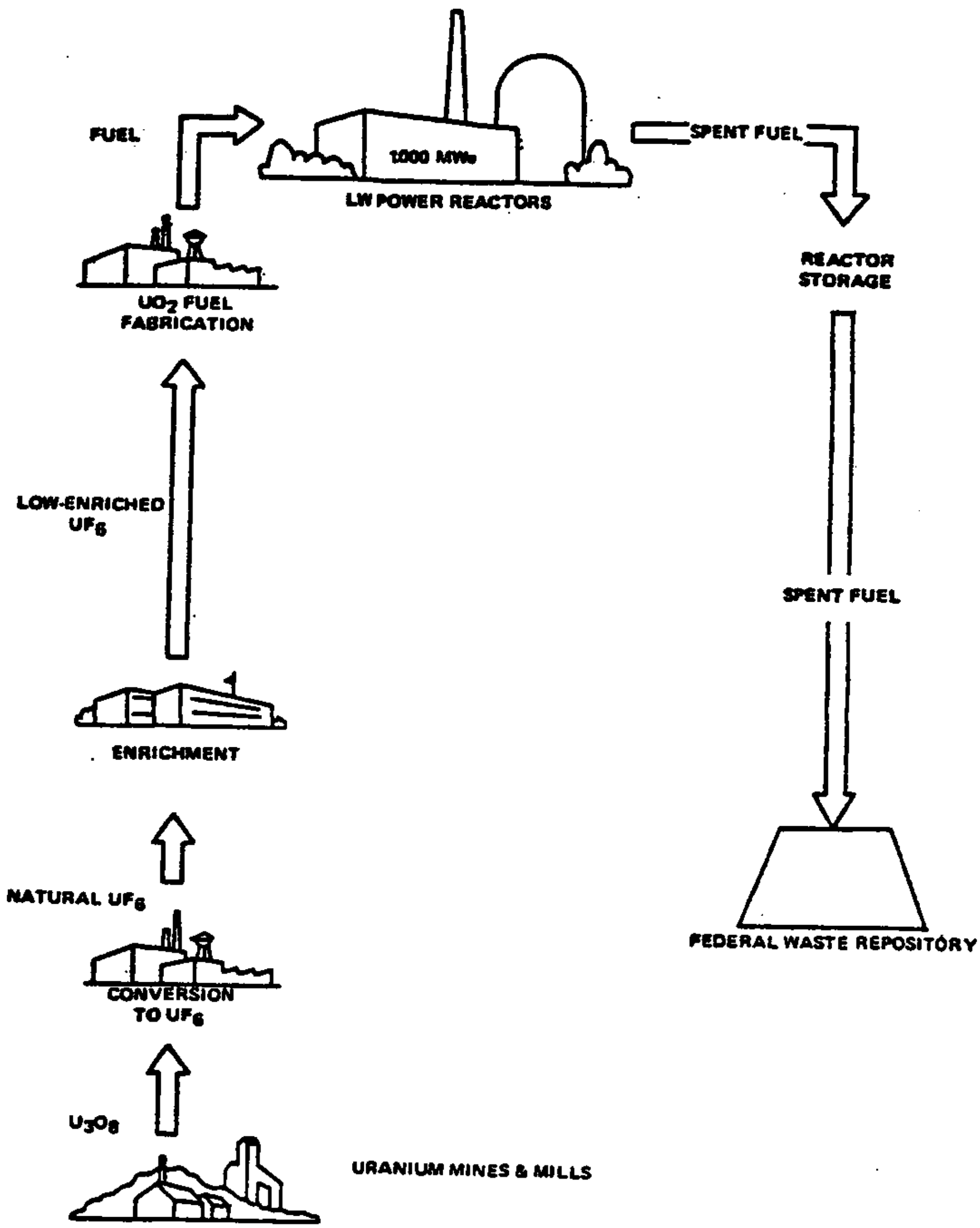


Figure D.2 Once Through Uranium Fuel Cycle liquid and solid wastes generated as part of milling operations has been already addressed in a separate rulemaking action and is not considered further in this appendix. Additional information can be located in NUREG-0706 (Ref. 3).

Yellowcake produced from milling operations is then shipped to conversion plants that convert U_3O_8 to uranium hexafloride (UF_6). The conversion process generates liquid and solid waste streams, most of which are recycled to recover uranium prior to storage in onsite ponds or reuse within the plant. Onsite storage at conversion facilities is presently regulated by NRC under 10 CFR Part 40. Small quantities of low-activity wastes contaminated with natural uranium are shipped offsite to licensed near-surface disposal facilities. These wastes are considered further in this appendix. Currently, there are two UF_6 conversion plants in operation in the United States; one plant is located in Region III and one in Region IV.

Following conversion, natural UF_6 is shipped to enrichment facilities for enrichment in fissile U-235. In this process, the U-235 content of the uranium is raised from natural concentrations (about 0.7 weight percent) to about 2 to 4 weight percent. Currently, three enrichment plants using the gaseous diffusion process are in operation and these are located at Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee. These plants are owned and operated by the federal government and wastes produced from plant operation are not sent to commercial disposal facilities. Hence, waste streams produced from uranium enrichment operations are not considered further in this appendix.

Enriched UF_6 is then shipped to commercial fabrication plants which convert the enriched UF_6 to uranium dioxide (UO_2) powder, produce UO_2 pellets, fabricate fuel rods containing the UO_2 pellets, and combine the fuel rods into fuel assemblies for use in light water reactors. Most of the liquids, sludges, and other wastes produced during the UF_6-to-UO_2 conversion process are presently being stored at the fabrication plants, although some wastes in the form of dry solids (principally CaF_2) contaminated with low levels of enriched uranium are being shipped offsite for disposal. Low-activity waste, principally trash, is also generated during the pelletizing and subsequent fabrication processes, and these waste streams are also shipped offsite for disposal. Table D-2 provides a summary of the current LWR fuel fabrication industry.

Fuel assemblies are then shipped to central station nuclear power plants, utilizing light water power reactors (LWR) for production of electrical power through use of the energy released during fission of the uranium fuel. During operations, waste is generated in a number of forms having specific activities ranging from low to moderately high levels. Much, if not most, of the waste is generated as a result of operating and maintaining plant processes which maintain concentrations of radiocontaminants in the reactor coolant and other process systems to low levels and reduce effluent releases from the plant to acceptable levels. The presence of such radiocontaminants in reactor cooling systems can result from activation of corrosion products or from leakage of fission products out of the fuel rods. The treatment and maintenance operations result in wet wastes such as filter sludges, spent resins, and evaporator bottoms, as well as compactible and noncompactible dry wastes. Liquids such

Table D.2 Current LWR Fuel Fabrication Industry

Licensee and Plant Location	Plant Feed Material	Plant Product	Plant Capacity (MTU/yr)	
			Current	Estimated 1985
Babcock & Wilcox Lynchburg, VA (2)*	UO_2 pellets (UF_6)	Fuel assemblies	230	830**
Babcock & Wilcox Apollo, PA (1)	UF_6	UO_2		†
Combustion Engineering Hematite, MO (3)	UF_6	UO_2		††
Combustion Engineering Windsor, CT (1)	UO_2 powder	Fuel assemblies	150	150
Exxon Nuclear Richland, WA (5)	UF_6	Fuel assemblies	665	1,030#
General Electric Wilmington, NC (2)	UF_6	Fuel assemblies	1,500	1,500
Westinghouse Electric Columbia, SC (2)	UF_6	Fuel assemblies	750	1,600

*NRC Region number.

**Babcock and Wilcox (B&W) plans to expand operations to increase capacity to 1,200 MTU/yr in the early 1990s. The capacity listed in the table for 1985 is an interpolation of present and future capacity. In addition, a UF_6 to UO_2 conversion operation will be added as well as a UO_2 pelletizing operation.

†Currently, the B&W Apollo plant converts UF_6 to UO_2 power and ships the UO_2 to its Lynchburg plant for fabrication into fuel assemblies.

††The Combustion Engineering (CE) Hematite plant produces UO_2, pellets or powder which are then transferred, to the CE Windsor plant for fabrication into fuel assemblies.

#Expanded to 1,030 MTU/yr in 1980.

Source: NRC Data

as evaporation bottoms are solidified, while other wet wastes such as ion-exchange resins are generally dewatered and packaged into containers for shipment. Some compaction is usually performed on compactible trash. The wastes are then generally shipped offsite for disposal.

Currently, there are 74 light water power reactors in operation in the United States, of which 48 are pressurized water reactors (PWR) and 26 are boiling water reactors (BWR). The locations of these operating reactors, as well as the locations of the reactors under construction, are shown in Figure D.1.

The fuel used in the reactors must be periodically replaced. Generally about one-third of the fuel in the reactor core is replaced approximately every 12 to 18 months. Most of this spent fuel is stored at the power stations within large spent fuel holding pools. A small fraction of this fuel, however, is presently stored offsite in fuel pools located within two facilities originally designed to reprocess the fuel. One facility (the Nuclear Fuel Service plant in West Valley, NY) suspended reprocessing operations in 1971 and the other (the General Electric facility in Morris, IL) never became operational. Additional facilities specifically constructed for storage of spent fuel may be constructed in the future; these may be located either at the operating reactors site or at away-from reactor (regional) sites.

Two basic options are available for the disposition of the spent fuel. One option is to treat the spent fuel as high-level waste and dispose of the spent fuel in a federal repository to be constructed and operated by the Department of Energy (DOE). Another option is to recycle the spent fuel as shown in Figure D.3. In this option, spent fuel would be shipped to a reprocessing plant which, using chemical separation processes, would recover residual uranium and plutonium for reuse in reactors. Recovered uranium would be shipped as UF_6 to an enrichment plant for enrichment in U-235. Recovered plutonium would be shipped as plutonium dioxide (PuO_2) powder to a mixed oxide (MOX) fuel fabrication plant where it would be combined with natural UO_2 and fabricated into MOX fuel rods. The MOX fuel rods would then be shipped to a fabrication plant where the MOX fuel rods would be combined with natural uranium fuel rods and assembled into fuel assemblies for reinstallation into LWRs. High level and transuranic wastes generated during reprocessing and MOX fuel fabrication operations would be shipped to a federal repository for disposal.

For the last four years, the policy of the United States as announced by former President Carter has been to defer the uranium recycle option. There are no reprocessing or MOX fuel fabrication facilities operating in the country and spent fuel removed from nuclear power reactors is currently being stored pending operation of a federal repository. It is possible that in the future, the country's policy on uranium fuel recycling may change. However, at present, the timing and extent of future fuel reprocessing and MOX fuel fabrication operations are speculative, as is the quantity of waste to be generated through such operations.

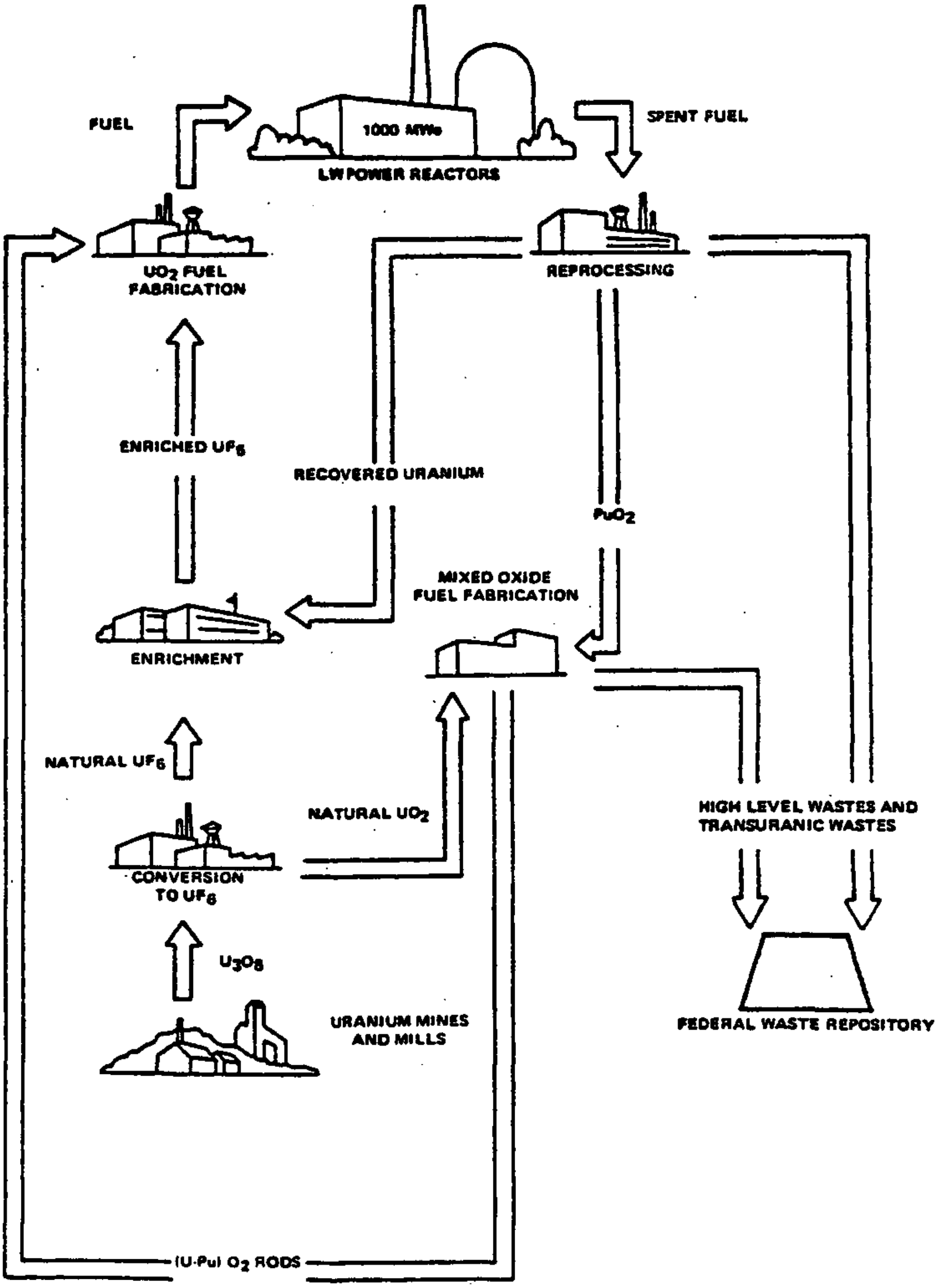


Figure D.3 Uranium and Plutonium Recycle Fuel Cycle

Nonfuel Cycle Waste Generators

Nonfuel cycle waste generators include approximately 20,000 facilities licensed by NRC or Agreement State agencies to use radioactive materials. Nonfuel cycle waste generators may be classified as either institutional or industrial.

Institutional waste generators include hospitals, medical schools and research facilities, colleges, and universities. Waste generation rates and waste characteristics vary significantly between institutional waste generators and it is therefore difficult to consider each type of institution as a separate waste generator. Therefore, all institutional facilities are considered as a single waste source in this appendix.

Industrial waste generators are also considered as a single waste source for the same reason, and include industries which produce and distribute radionuclides, manufacture materials containing radioisotopes for industrial uses, and use radioisotopes in laboratory studies, instruments, devices, and manufacturing processes. Industrial waste generators have not been surveyed to as great an extent as other types of waste generators.

2.2 Central Station Nuclear Power Plants

Central station nuclear power plants presently in operation in the United States include 74 light water reactors (LWRs) and a single high temperature gas-cooled reactor (HTGR). The waste generated by the single HTGR is volumetrically and radiologically negligible compared with the wastes generated by LWRs (Ref. 4), and is therefore not considered further in this appendix. Electricity for commercial use is also generated as a byproduct of the Hanford "N" plutonium production reactor and the Shippingport light water breeder reactor. Wastes generated by these facilities are disposed in facilities operated by the Deparment of Energy (DOE) and not in commercial disposal facilities.

The majority of the LWR waste streams are generated by operation of in-plant liquid radwaste processing systems. The basic functions of these processing systems are to reduce the accumulation of radioactive contaminants within the plant and to reduce the amount of these contaminants released from the plant. More detailed descriptions of these systems can be found elsewhere (Ref. 5). During these processes, radioactive contaminants are concentrated in several forms.

Two types of LWRs are in operation today: pressurized water reactors (PWRs) and boiling water reactors (BWRs). Waste streams common to PWRs and BWRs can be divided into "process wastes" and "trash." Process waste streams include ion exchange resins, concentrated liquids (evaporator bottoms), filter sludges. Cartridge filters are another form of process waste but are used much more extensively in PWRs than in BWRs. Trash waste streams can be divided into compactible trash and noncompactible trash. Another waste stream common to both types of LWRs and generated on an infrequent basis consists of nonfuel reactor core components. Wastes from future LWR decontamination operations may also be generated. The LWR processing systems that result in the generation of the process waste streams are briefly outlined in Table D.3.

Table D.3 Major Sources of Process Wastes in LWRs

BWRs	PWRs
1. Application of Ion Exchange Resins	
Condensate polishing system	Condensate polishing system
Reactor water cleanup	Chemical and volume control system
Clean radwaste system	Boron control system
Dirty radwaste system	Spent fuel pool cleanup
Chemical waste system	Steam generator blowdown system
Spent fuel pool cleanup	Miscellaneous waste system
	Chemical waste system
2. Sources of Liquids Concentrated by Evaporation	
Regeneration of resins	Regeneration of resins
General decontamination waste liquids	General decontamination waste liquids
System effluents from:	System effluents from:
Clean radwaste	Liquid radwaste
Dirty radwaste	Chemical radwaste
Chemical radwaste	Laundry waste
Laundry waste	Steam generator blowdown
3. Application of Precoat Filters and Cartridge Filters	
Condensate polishing system	Steam generator blowdown
Reactor water cleanup	Condensate polishing system
Spent fuel pool cleanup	Boron control system
Equipment and floor drains	Spent fuel pool cleanup
Chemical waste system	Laundry waste system
Laundry waste system	

Ion Exchange Resins

Processes involving ion exchange media are frequently used in LWRs to remove dissolved radioactivity from liquid streams. Ion exchange media usually consists of organic resins, which can be cation or anion resins, or a mixture of both. Inorganic zeolite ion exchange media has also been used in some cases. The resins (or other ion exchange media) are usually packed into cylindrical tanks (ion exchange columns or demineralizers) and the liquid containing the specific contaminant is passed through the resin column. In this process, dissolved radiocontaminants chemically displace ions in the resin and become physically bound to the resin. When an ion exchange bed can no longer perform its function (following depletion), it is replaced or regenerated. The old bed is typically transferred as a slurry out of the tanks into a shipping container (generally referred to as a liner), where excess water is removed prior to transfer to a disposal facility. Removal of free water is termed dewatering; dewatered ion exchange media however, can still contain between 42 and 55% water by weight (Ref. 6), in addition to interstitial liquid. In general, the liners are transported in casks that are shielded for radiation protection.

Concentrated Liquids

Concentrated liquid waste may be produced by the evaporation of a wide variety of LWR liquid streams. Many systems generating these liquid streams are interrelated (see Table D.3). The waste consists of liquids with an elevated suspended and dissolved solids content, and also consists of sludge resulting from supersaturation during evaporation. Newer LWR plants, especially PWRs, often have several evaporators, each dedicated to concentrating a particular liquid stream. Existing PWRs usually concentrate boric acid waste solutions to about 11% solids by weight, and BWRs usually concentrate liquids containing sodium sulfate to about 25% solids by weight (Ref. 6). Other types of solutions (e.g., laundry liquids, laboratory drains) are concentrated to about 25% solid by weight (Ref. 6). These concentrated liquids are currently solidified in various matrix materials including urea-formaldehyde and cement prior to transfer to a disposal facility.

Filter Sludge

Filter sludge is waste produced by precoat filters and consists of filter aid and waste solids retained by the filter aid. Diatomaceous earth, powdered mixtures of cation and anion exchange resins, and high purity cellulose fibers are common filter aids. These materials are slurried and deposited (precoated) as a thin cake on the initial filter medium (wire mesh, cloth, etc.). The filter cake removes suspended solids from liquid streams. Precoat filters using powdered resins also remove dissolved solids but are not as effective as mixed bed ion exchange columns (deep bed demineralizers) due to the shorter contact time of the liquid with the resin. Precoat filters are used much more extensively in BWRs than in PWRs (see Table D.3). Precoat filtration may be used in conjunction with ion exchange columns and evaporation, or it may be the only form of treatment removing suspended solids from a particular liquid stream.

Cartridge Filters

Cartridge filters contain one or more disposable filter elements. These elements may be typically constructed of woven fabric, wound fabric, or pleated paper supported internally by a stainless steel mesh as well as pleated or matted paper supported by an external stainless steel basket. Paper filter elements are often impregnated with epoxy. Woven fabric filters are typically constructed of cotton and nylon. Cartridge filters are effective in removing suspended solids, but do not have the ion exchange capability of precoat filters or demineralizers. They are used much more extensively in PWRs than BWRs, and their typical uses in LWRs are similar to those of precoat filters (see Table D.3). Many plants use cartridge filters in conjunction with ion exchange columns, evaporators, and precoat filters. Currently, these cartridge filters are usually packed in 55-gallon drums (between 3 to 12 per drum) prior to transfer to a disposal facility (Ref. 6).

Trash

Trash is the most varied waste stream generated by LWRs and can contain everything from paper towels to irradiated reactor internals. Some of the materials that have been identified in the past as having been shipped as trash are listed in Table D.4.

A recent survey (Ref. 6), found that compactible and noncompactible items are frequently shipped in the same container and that packaging small pieces of activated metal with relatively innocuous materials is common. Such factors make characterization of trash difficult. In general, compactible trash contains more combustible material (e.g., paper, plastic), and noncompactible trash contains more metallic components (e.g., pipes and failed equipment). It is usually assumed that the volume percentage of compactible trash and combustible trash are the same. Similarly, the volume percentage of noncompactible trash and noncombustible trash are assumed to be the same.

Other Waste Streams

Nonfuel reactor components consist of fuel channels, control rods, control rod channels, shim rods, in-core instrumentation, and flux wires. Many of these components are exposed to the primary reactor coolant and all are exposed to the in-core neutron flux.

LWR decontamination waste is expected to be produced in the future by routine full-scale decontamination of LWR primary coolant systems. The components included in these systems include the reactor core, the reactor pressure vessel, system piping, various pumps, and turbines. The purpose of decontamination is to reduce in-plant occupational radiation exposures by removing crud accumulated on surfaces that are in contact with the primary coolant. It is expected that typical waste streams generated during these future routine decontamination operations will include such streams as ion-exchange resins used to process the decontamination solutions and solidified evaporator bottoms. The wastes are projected to contain large quantities of chelating agents.

2.3 Other Nuclear Fuel Cycle Facilities

Other nuclear fuel cycle waste streams considered in this appendix include process wastes from uranium hexafluoride conversion (UF_6) plants and fuel fabrication facilities, and trash from fuel fabrication facilities. These wastes are generally not well characterized. No data could be found for trash from UF_6 conversion facilities.

Table D.4 Material Shipped as LWR Trash

Material	BWRs C*	BWRs N*	PWRs C	PWRs N
Anti-contaminant clothing			X	
Cloth (rags, mops, gloves)	X		X	
Conduit				X
Contaminated dirt	X	X		
Contaminated tools and equipment				
Hand tools	X	X		
Eddy current equipment				X
Vessel inspection equipment				X
Ladders		X		X
Lighting fixtures				X
Spent fuel racks				X
Scaffolding		X	X	
Laboratory equipment			X	X
Filters				
Filter cartridges	X	X		
HEPA filters		X	X	X
Respirator cartridges	X			
Glass	X	X	X	
Irradiated Metals				X
Flux wires				X
Flow channels		X		
Fuel channels		X		X
In-core instrumentation				X
Poison channels		X		
Shim rods				X
High density concrete block				X
Miscellaneous metal	X	X		X
Aerosol cans		X		
Buckets	X			
Crushed 55-gal drums		X		
Fitting		X		
Pipes and valves		X		X
Miscellaneous wood	X	X	X	X
Paper	X		X	
Plastic				
Bags, gloves, shoe covers	X	X	X	
Sample bottles	X			
Rubber	X			X
Sweeping compounds		X		

*C: compactible, combustible;
N: noncompactible, noncombustible.

Processed uranium ore or yellowcake containing about 0.7 percent fissile U-235, must be enriched in U-235 content prior to utilization as fuel in LWRs. Prior to enrichment by the gaseous diffusion process (the major technology currently used for enrichment), the uranium must be converted to UF_6, which is an easily-volatilized compound suitable for this process. During this process in UF_6 conversion facilities, liquid and solid wastes are generated. Many of these waste streams are recycled in the plant to recover uranium. Some process wastes, however, are shipped for disposal. These wastes consist primarily of calcium fluoride generated in hydrogen fluoride gas scrubbers, bed materials from fluidized bed reactors, and lime from treatment of liquid effluents.

Fuel fabrication is the final step before uranium fuel is utilized in LWRs. In fuel fabrication facilities, enriched UF_6 from gaseous diffusion plants is converted into a solid form (usually uranium dioxide) and then into fuel pellets, fuel rods, and finally fuel assemblies. A large portion of the wastes generated during these operations are recycled to recover uranium. Process wastes shipped for disposal include limestone used in calcium fluoride, scrubbers, calcium fluoride, oxides from calciners, filter sludges, and small amounts of oils. Trash shipped for disposal includes paper, plastic, equipment, and miscellaneous combustible materials.

2.4 Institutional Facilities

Institutional waste generators include colleges and universities, medical schools, research facilities, and hospitals. These institutions use radioactive materials in many diverse applications. Sealed sources and foils are widely used as integral parts of analytical instruments and irradiators. Labelled pharmaceuticals and biochemicals are used in nuclear medicine for therapy and diagnosis, and in biological research to study the physiology of humans, animals, and plants. Radioactive materials are also used by many other academic disciplines such as chemistry, physics, and engineering. Radioactive waste streams are also produced by institutions as a byproduct of research using neutron activation analysis, particle accelerators, and research reactors.

Based upon information received from surveys (Refs. 7, 8), institutional wastes may be classified into four volumetrically significant groups: liquid scintillation vials containing scintillation fluid (shipped with absorbent materials), other liquids (solidified or shipped with absorbent materials), biological wastes (shipped with absorbent materials and lime), and trash. In addition to these streams, institutional facilities generate two volumetrically smaller waste streams, accelerator targets and sealed sources, that have been included under the next section on industrial wastes.

Liquid scintillation counting techniques are used to some extent by nearly all fuel cycle and nonfuel cycle waste generators; however, applications in biological research produce the major volumes of waste scintillation vials and fluids. The vials are made of glass and occasionally polyethylene, and are usually about half full of counting fluid. Flammable organic solvents (e.g., toluene, benzene, xylene) comprise the major constituents of scintillation fluids (Refs. 7, 8).

Absorbed liquids have not been as well characterized as liquid scintillation vials, in part because the composition of absorbed liquids is not constrained by the requirements of liquid scintillation counting techniques. Approximately 50 percent of these absorbed liquids are scintillation fluids (Ref. 7). The remaining liquids are aqueous and organic solvents generated by diverse preparatory and analytical procedures such as wastes from elution of Tc-99m generators, radioimmunoassay procedures, and tracer studies.

Biological wastes are generated primarily through research programs at universities and at medical schools. The waste consists of animal carcasses, tissues, animal bedding, and excreta, as well as vegetation and culture media. Radioactive excreta from humans undergoing diagnostic or therapeutic procedures that use radioactive materials are not included since virtually all such materials are discharged to sewers (Ref. 8).

Institutional trash consists almost entirely of materials that are both compactible and combustible. It generally consists of paper, rubber or plastic gloves, disposable and broken labware, and disposable syringes.

2.5 Industrial Facilities

Wastes from industrial facilities may be grouped into five streams that are relatively small in volume but high in activity: medical isotope production wastes, highly activated wastes, tritium manufacturing wastes, sealed sources, and accelerator targets. In addition, there are two groups of industrial facilities that generate four volumetrically significant waste streams containing relatively low levels of radioactivity: (1) facilities using source and special nuclear materials (generating trash and other miscellaneous wastes), and (2) other facilities that use radioactive material and generate low specific activity wastes containing less than 3.5 Ci/m^3 (0.1 Ci/ft^3). Waste from these facilities is also divided into trash and miscellaneous other wastes.

Medical isotope production wastes result from production of fission isotopes for medical use through irradiation of very highly enriched uranium. Although some institutions using large quantities of radioactive materials in research and medical applications produce their own radioactive isotopes, most of these radionuclides are produced by industrial radioisotope generators. The wastes generated consist of paper, plastic, glass, metal, and aqueous solutions of inorganic salts. The aqueous solutions are solidified in small metal containers and packed with low-specific-activity trash in common containers (55-gallon drums) for shipment.

The high-specific-activity industrial waste stream is a generic stream that includes miscellaneous wastes of relatively high activity, which is arbitrarily defined as an activity that exceeds 3.5 Ci/m^3 or 0.1 Ci/ft^3. High-specific-activity industrial wastes are expected to include activated metal and equipment produced by accelerators, activated metal and equipment from research reactors and subcritical assemblies, and activated metal from neutron generators.

Tritium is the most widely used of all radioisotopes. In addition to applications in biological research and medicine, it is used in a wide variety of products, most commonly in illuminators. Although tritium is a naturally occurring isotope, artificial production of tritium is more economical than enrichment of natural tritium. The waste generated during manufacturing of tritium products is assumed to consist of lithium fluoride, trash, plastic, glass, and a small quantity of metal. It is also assumed to contain waste chemicals that are generated by conversion of tritium gas to tritiated water and by incorporation of tritium into chemical compounds.

Sealed sources containing radioactive materials other than source and special nuclear materials are encapsulated to prevent leakage of the radioactive material. Low-activity sealed sources and foils are also used as calibration and reference standards for many types of radiation detectors. High-activity sealed sources are used in neutron generators as both generators and targets, and in medical and industrial irradiators. Other examples of industrial sources include density gagues, well logging sources, radiography sources, x-ray fluorescence tubes, static eliminators, and so forth. This waste stream includes industrial sealed sources as well as sealed sources from institutions.

Accelerator targets are used to produce radionuclides by direct bombardment with charged particle beams or by indirect reactions of the target fragments with other materials. Accelerator targets are also used to study nuclear reactions and to produce and study the properties of various subatomic particles. Targets from institutional sources are also included in this waste stream. Spent targets are commonly made of titanium foils containing absorbed tritium.

Source and special nuclear material wastes are produced outside the nuclear fuel cycle by industries that process and fabricate depleted uranium and manufacture chemicals or products containing uranium. Although little information is available, it appears that most of the waste is generated through processing of depleted uranium. These wastes are distinguished from other non-fuel cycle wastes by the almost complete absence of radionuclides other than those included in the definitions of source and special nuclear materials. They are considered as two streams: trash and other miscellaneous wastes.

The last group of waste streams are low specific activity wastes containing less than 3.5 Ci/m^3 or (0.1 Ci/ft^3). The major contributors to this group of streams are the industrial equivalents of institutions. Such waste is generated by pharmaceutical companies, independent testing laboratories, and analytical laboratories. The characteristics of low specific activity industrial wastes are expected to resemble those of institutional wastes; however, since the limited data available is insufficient to justify separate waste streams for scintillation fluids, adsorbed liquids, and biowastes, they are also considered as two streams: trash and other miscellaneous wastes.

3. WASTE CHARACTERISTICS

This section presents information on the volumes and radiological characteristics of the waste streams projected to be generated to the year 2000. The waste streams considered are those discussed in the previous chapter. Information on the packaging characteristics of these waste streams can be found in Section 4.

The following symbols will be used for the major waste generators for the remaining discussion in this appendix:

Symbol	Facility
P	PWRs
B	BWRs
L	LWRs
F	Fuel Fabrication Facilities
U	UF_6 Conversion Plants
I	Institutional Facilities
N	Industrial Facilities

The waste streams outlined in the previous section will be discussed in four major groups: LWR process wastes, trash, low specific activity wastes, and special wastes. These groups and the waste streams that make up each group are presented in Table D.5.

These streams are combined into these four groups based upon similarities in their macroscopic characteristics. For example, LWR process wastes are usually wet wastes that have comparatively higher specific activities than either the trash group or the low specific activity group. The trash group is self-evident and contains most of the combustible LLW generated. The low specific activity waste group includes all the streams containing comparatively small activities that are not included in the LWR process waste group or the trash group. The "special" waste group contains streams that contain relatively high concentrations of radioactivity and are small in volume when compared with the other three groups. This grouping of waste streams simplifies the application of generic waste treatment technologies and disposal procedures to general groups, thereby increasing the flexibility of the data base.

As shown in Table D.5, six of the waste streams have been separated into two components, and the additional six streams resulting from this separation have been denoted by a plus sign after the waste generator symbol (I or N) instead of the usual minus sign. These streams are industrial SSTRASH, industrial LOTRASH, institutional COTRASH, institutional LIQSCLV, institutional ABSLIQD, and institutional BIOWAST. The reason for this separation is to identify the volumes of waste from generators that can more easily implement their own waste treatment processes (e.g., comparatively large facilities, denoted by a minus sign), and the waste from those generators that cannot do the same (e.g., comparatively small facilities, denoted by a plus sign).

The waste streams that are not considered in detail in this appendix (e.g., decommissioning and reprocessing wastes) can be classified as a fifth group of wastes. These streams are briefly discussed in Section 6.

Table D.5 Waste Groups and Streams

Waste Stream	Symbol
Group I: LWR Process Wastes	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartrides	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
Group II: Trash	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-COTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS* Trash (large facilities)	N-SSTRASH
Industrial SS* Trash (small facilities)	N+SSTRASH
Industrial Low Trash (large facilties)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
Group III: Low Specific Activities Wastes	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV** Waste (large facilities)	I-LIQSCVL
Institutional LSV** Waste (small facilities)	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS* Waste	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
Group IV: Special Wastes	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
High Activity Waste	N-HIGHACT

*SS: Source and special nuclear material
**LSV: Liquid Scintillation vial

3.1 Volume Projections

This section discusses NRC staff estimates of waste volumes expected to be routinely generated on a regional basis and disposed through the year 2000, considering current waste generation rates as well as projected waste generation growth rates. The regions used in the projections correspond to the five NRC regions as shown in Figure D.1. In developing the projections, nuclear fuel cycle waste volumes were assumed to be proportional to the nuclear electrical generation capacity. Nonfuel cycle waste volumes were assumed to grow at a linear rate based upon a least squares fit of existing data on individual waste streams.

3.1.1 Fuel Cycle Wastes

Projections of nuclear electrical generation capacity were principally based upon a review of information on nuclear power stations currently built and operable, under construction, planned or on order (Refs. 9-12). Projections made by NRC licensing staff regarding start-up times were also used to supplement the basic information (Ref. 13). Based upon this data, two scenarios were developed for central station nuclear power plant construction--a "low" scenario and a "high" scenario. The low scenario assumes that construction continues on power reactors that are already under construction but that any additional construction of power reactors essentially ceases until at least the late 1980s. The high scenario assumes that construction commences on a number of additional plants, including those units planned as of the beginning of 1980, as well as plants for which construction has been deferred indefinitely. The projected regional capacity by the year 2000 for both scenarios is presented in Table D.6. Also shown, in parentheses, is the number of LWRs projected to be operating. As shown, the total U.S. capacity by the year 2000 is projected to range between 146,000 and 169,000 MW(e).

Table D.6 Projected LWR Capacity by the Year 2000, in MW(e)

	Low Scenario*		High Scenario*	
Region	PWR	BWR	PWR	BWR
1	17,691(20)	12,216(14)	22,411(24)	14,516(16)
2	38,958(39)	17,239(16)	44,058(43)	18,173(17)
3	18,785(21)	13,550(18)	22,295(24)	13,550(18)
4	8,901(8)	3,078(3)	8,091(8)	4,228(4)
5	15,580(14)	1,165 (2)	18,100(17)	3,719(4)
	97,805(102)	47,248(53)	114,955(116)	54,186(59)
	146,333(155)		169,141(175)	

*Note: Since the original projections were made, construction of a 907 MW(e) PWR (North Anna Unit 4 in Region II) has been definitely cancelled. Startup of another facility--Allens Creek, a 1150 MW(e) BWR located in Region IV--has been delayed by two years.

It is believed that the projections in Table D.6 effectively provide a lower and upper bound of the generating capacity that would be available by the year 2000. As of June 30, 1979, 27 units were listed as "planned," representing a capacity 32,726 MW(e) (Ref. 9). Of these 27 units, 19 had definite projected start-up dates. Only one year later, 11 of these original 27 units had been canceled (13,202 MW(e)). Out of the remaining 16 units, three have been deferred indefinitely; only five (5,910 MW(e)) are listed as having definite start-up dates, (Ref. 12). Of these five units, applications for construction have been submitted to NRC for only three of them (Allens Creek Unit 1, Pebble Springs Units 1 and 2), and no construction permits for these three units have to date been issued. It would not be surprising, therefore, if no more than half of the planned units discussed above were actually constructed by the year 2000. The slowdown in construction of and planning for new nuclear generating facilities is probably due to a number of reasons--e.g., a lessening in the demand for additional electrical generating capacity, the slowdown in the economy coupled with the large costs of constructing a nuclear power station, and public concern over the safety of nuclear power.

It is possible that interest in building new nuclear generating units may increase in the future. However, it takes a number of years to construct and license a nuclear power station. Assuming that it requires a conservative minimum of 12 years from the time of initial application to start-up of a single unit, an application would have to be tendered by no later than 1988 in order to be operating by the year 2000.

Therefore, only those planned units for which an application has already been received by NRC or received within the next few years could realistically contribute to the waste generated by LWRs by the year 2000. Finally, any delays in the start-up times for units currently planned or under construction would act to further reduce the amount of waste produced by LWRs by the year 2000.

A summary of volumes and gross specific activities of LWR waste streams projected to be generated on a "per MW(e)-yr" basis is presented as Table D.7. The data used to construct this table were principally obtained from ONWI-20 (Ref. 6), and are averages based upon NRC staff estimates of the use of condensate polishing systems (CPS) as part of water treatment in LWRs. For the table, 60% of BWRs were assumed to use deep-bed CPS and 40% precoat CPS; about half of PWRs were assumed to use CPS and about half were not. The volumes shown, with the exception of cartridge filters, are for "untreated" wastes. Concentrated liquids (evaporator bottoms) are reported as generated prior to solidification. Resins and filter sludges are reported as dewatered, and the trash streams are reported as generated prior to such processing options as incineration or compaction. The volumes for cartridge filters are given as packaged for shipment.

Projected volumes of activated nonfuel core components (e.g., poison curtains, flow channels, and control rods) are difficult to characterize. LWR core components are replaced on an infrequent basis, and frequently, small components are shipped to disposal facilities by placing the components in the middle of

Table D.7 Summary of Principal LWR Waste Streams

Waste Type	Volumes (m^3/MW(e)-yr) BWR	PWR	Activity (Ci/MW(e)-yr) BWR	PWR
Resins	0.081	0.081	1.14	0.40
Concentrated Liquids	0.223	0.124	0.20	0.11
Filter Sludge	0.179	.002	1.40	0.006
Cartridge Filters	0	.011	0	0.12
Trash				
Total	0.326	0.326	0.402	0.063
Compactible	0.221	0.215	0.005	0.005
Noncompactible	0.105	0.111	0.397	0.058
Totals:	0.808	0.478	3.29	0.699

a container of otherwise low activity material such as trash. For this appendix, LWRs were projected to generate about 1 m^3 (35 ft^3) of core component waste per GW(e)-yr at a gross specific activity of about 113 Ci/m^3 (4000 Ci/ft^3). This projection was based upon a review of disposal facility radioactive shipment records (Ref. 14). NRC staff believe that these projections are likely to be conservative, as the noncompactible trash stream discussed above probably already contains activated core components (i.e., core components are to a certain extent counted twice in this appendix).

Other waste streams that are difficult to project will be generated by periodic decontamination of the primary coolant systems of LWRs. The purpose of such full-scale primary decontamination operations is to reduce plant personnel exposure by removing crud accumulated on surfaces in contact with the primary coolant. Although full-scale primary coolant decontamination operations have not been routinely performed in the past, NRC has fairly recently (October 1980) published an environmental statement regarding such an operation being performed at the Dresden Unit 1 nuclear power station. Dresden 1 is a 200 MW(e) dual-cycle BWR which over its 20 year operating life, has built up a thin layer of radioactive oxide deposits (principally Co-60) over the inner surfaces of pipes, valves, pumps, etc. In the decontamination process for Dresden Unit 1, a decontamination solution is circulated and flushed through the coolant system, which dissolves the crud deposits. The decontamination solution is then removed from the coolant system and processed through an evaporator. The evaporator bottoms are then solidified in vinylester (a synthetic polymer), which are then shipped offsite for disposal. Since the solidified waste will contain a large quantity of chelating agents, the waste will be disposed only at a disposal facility located in an arid environment and segregated from other waste by at least 3 meters of soil (Ref. 15).

Although the Dresden-1 decontamination operation can be considered in many respects a prototype of future primary coolant plants, it is still difficult to project future volumes and other characteristics of decontamination wastes. There may be a number of possible decontamination processes utilized--e.g., from dilute chemical processes on an annual basis to more concentrated processes at intervals of several years--and the waste streams generated may vary in kind (e.g., resins, solidified liquids) and in volume from operation to operation and plant to plant. Other plant-specific factors which would influence the volumes, radioactivity content, and other characteristics of the wastes generated would include the operating history of the plant (e.g., history of fuel failures), the design of the plant and liquid clean-up and processing systems, the chemistry of the primary coolant, and the length of time between decontamination operations. Institutional matters such as the policies of a specific utility could also be a consideration.

Notwithstanding this uncertainty, NRC staff believe that wastes generated from routine full-scale decontamination of reactor primary coolant systems should be represented in the low-level waste source data base. For this appendix, it is assumed that every operating LWR undergoes a full-scale primary coolant decontamination operation every 5 to 10 years using a dilute chemical decontamination process (Ref. 16). This results in BWR and PWR resin waste streams of approximately 95 and 47.5 m^3, respectively, per operation. This assumes that the volumes of contaminated liquid generated per operation are 760 m^3 and 380 m^3, respectively, and assumes that approximately 0.125 m^3 of dewatered resin is required to process 1 m^3 of contaminated liquid. Contained in these resins will be significant quantities of chelating agents and other decontamination chemicals.

Projections for fuel fabrication wastes were obtained from ONWI-20 (Ref. 6), and are estimated to be about 122 m^3 per GW(e) of installed LWR capacity. The estimated average activity of these wastes is 8.5 E-4 Ci/m^3. Fuel fabrication process wastes were estimated to be about 15% of this total volume. Of the remaining volume, approximately 85% is estimated to be combustible and 15% noncombustible. Uranium conversion waste projections were obtained from References 2 and 28, and supplemented by data obtained from disposal facility records (Ref. 5). The estimated volume and activity are 9.6 m^3/GW(e) and 3.8 E-4 Ci/m^3, respectively.

3.1.2 Nonfuel-Cycle Wastes

Projections of total activities, volumes, and regional dependency through the year 2000 for nonfuel-cycle wastes were developed from a number of sources. Included are medical and bioresearch wastes, wastes from production of medical isotopes, industrial high-activity wastes, industrial tritium wastes, and industrial low-activity wastes. Starting with 1980 waste generation rates, nonfuel-cycle wastes volumes and activities are assumed to increase at linear rates calculated by assuming least-squares fits to existing data.

Projections of medical and bioresearch wastes, including dry solids, scintillation vials, absorbed liquids, biological wastes (animal carcasses, tissues, etc.), and accelerator targets, were derived principally using NUREG/CR-0028 (Ref. 7) and its follow-up report NUREG/CR-1137 (Ref. 8). Based upon this data, total volumes of medical and bioresearch wastes in 1980 were estimated to be 19,120 m^3, while total activity was estimated to be 4412 Ci. Total volumes and activities are estimated to increase at a rate of 1280 m^3 and 295 Ci per year. Dry solids constitute 42% of the total volume, scintillation vials 39%, absorbed liquids 10%, biological wastes 9% and accelerator targets 0.2%. Fifty-six percent of the activity is projected to be contained in accelerator targets. The regional distribution of medical and bioresearch wastes are assumed to correspond to the institutional population surveyed (Ref. 8)--i.e., Region 1: 31%; Region 2: 22%; Region 3: 27%; Region 4: 8%; and Region 5: 12%.

A summary of estimated current and projected future volumes and activities in industrial wastes is provided as Table D.8. Compared to institutional wastes (medical and bioresearch wastes) and fuel cycle wastes, less information is available for industrial waste streams. Consequently, industrial waste streams are more difficult to characterize.

Table D.8 Estimated Current and Projected Future Volumes and Activities of Industrial Waste Streams

	Volumes (m^3)		
Waste Streams	Current	Added per year	Gross Specific Activity (Ci/m^3)
Medical isotope production waste:			
	192.6	13.8	573
Industrial high-activity waste (> 3.5 Ci/m^3):			
o Sealed sources	5.3	.36	5700
o Other high activity waste	74.4	5.0	210
Industrial low-activity waste (< 3.5 Ci/m^3):			
o Source and special nuclear material	12,050	807	0.03
o Other low activity waste	4,608	309	0.03
Industrial tritium waste:			
	99.3	6.7	2326

Estimates of medical isotope production waste were based upon consideration of disposal facility radioactive shipment records (Ref. 14). Wastes from this source are generated in Region 1.

Industrial high and low activity wastes were somewhat arbitrarily divided at a concentration level of 3.5 Ci/m^3 (0.1 Ci/ft^3). Estimates of industrial high and low activity wastes were based upon consideration of disposal facility radioactive shipment records (Ref. 14). The regional distribution of these wastes was assumed to be the same as that of the medical and bioresearch waste streams.

Industrial tritium manufacturing waste volumes were estimated from a number of sources as described in Reference 14. For this appendix, three quarters of the tritium waste was assumed to be generated in Region 1, the region with the major user of tritium. The remainder was assumed to be divided equally among the other 4 regions.

3.1.3 Volume Projections to the Year 2000

The total untreated waste volumes projected to be generated to the year 2000 are summarized in Table D.9. In generating this table, the waste volumes projected to be generated in Regions 4 and 5 were found to be significantly less than the other three regions and so were combined into one region. The following assumptions have been used in estimating these waste stream volumes:

- The P-IXRESIN, B-IXRESIN, P-FSLUDGE, and B-FSLUDGE waste stream volumes are assumed to be "dewatered" volumes.
- The P-CONCLIQ and B-CONCLIQ waste streams are assumed to be concentrated to the levels currently practiced in the industry; the solids content (by weight) of these streams range from 2% to 20% in PWRs and 7 to 50% for BWRs with an average of about 11% for PWRs and 25% for BWRs (Ref. 6).
- The P-FCARTRG waste stream is that of the packaged waste.
- None of the LWR trash waste streams are assumed to be treated by compaction or by incineration.
- The I-LIQSCVL, I+LIQSCVL, I-ABSLIQD, and I+ABSLIQD waste stream volumes represent volumes prior to packaging. Estimated shipping volumes include two volume parts absorber to one volume part waste (Ref. 8).
- For calculational convenience, the fraction of the liquid scintillation vial fluid volume currently estimated to be shipped as part of the ABSLIQD waste stream (about 50% by volume) has been included in the LIQSCVL waste streams. The volume of the LIQSCVL stream represents the volume of the vials containing the scintillation fluid; the actual fluid volume is assumed to be one-half of the vial volume (Ref. 17).

Table D.9 "Untreated" Waste Volumes Projected to be Generated to the Year 2000 per Region (m^3)

	REGION 1		REGION 2		REGION 3		REGION 4	
	VOL	%	VOL	%	VOL	%	VOL	%
P-IXRESIN	6.93E+03	.79	1.30E+04	1.34	6.59E+03	1.00	8.14E+03	1.25
P-CONCLIQ	4.87E+04	5.54	9.12E+04	9.45	4.63E+04	7.06	5.72E+04	8.79
P-FSLUDGE	8.56E+02	.10	1.60E+03	.17	8.14E+02	.12	1.01E+03	.15
P-FCARTRG	4.35E+03	.50	8.16E+03	.84	4.14E+03	.63	5.12E+03	.79
B-IXRESIN	2.10E+04	2.39	2.51E+04	2.60	2.05E+04	3.12	9.67E+03	1.49
B-CONCLIQ	5.79E+04	6.59	6.93E+04	7.17	5.64E+04	8.60	2.67E+04	4.10
B-FSLUDGE	4.65E+04	5.30	5.57E+04	5.77	4.54E+04	6.92	2.14E+04	3.30
P-COTRASH	8.49E+04	9.66	1.59E+05	16.47	8.07E+04	12.31	9.97E+04	15.33
P-NCTRASH	4.36E+04	4.96	8.16E+04	8.45	4.14E+04	6.32	5.12E+04	7.87
B-COTRASH	5.74E+04	6.54	6.87E+04	7.12	5.60E+04	8.54	2.65E+04	4.07
B-NCTRASH	2.72E+04	3.10	3.26E+04	3.38	2.66E+04	4.05	1.26E+04	1.93
F-COTRASH	4.72E+04	5.37	1.18E+05	12.22	0.	0.	7.08E+04	10.88
F-NCTRASH	8.34E+03	.95	2.09E+04	2.16	0.	0.	1.25E+04	1.92
I-COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
I+COTRASH	4.36E+04	4.97	3.10E+04	3.21	3.80E+04	5.79	2.81E+04	4.33
N-SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N+SSTRASH	8.98E+04	10.22	1.80E+04	1.86	3.59E+04	5.48	3.59E+04	5.52
N-LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
N+LOTRASH	1.52E+04	1.73	1.01E+04	1.05	1.52E+04	2.32	1.01E+04	1.56
F-PROCESS	1.56E+04	1.78	3.91E+04	4.05	0.	0.	2.34E+04	3.61
U-PROCESS	0.	0.	0.	0.	1.41E+04	2.14	1.41E+04	2.16
I-LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I+LQSCNVL	1.52E+04	1.73	1.08E+04	1.12	1.33E+04	2.02	9.83E+03	1.51
I-ABSLIQD	1.73E+03	.20	1.23E+03	.13	1.51E+03	.23	1.12E+03	.17
I+ABSLIQD	1.73E+03	.20	1.23E+03	.13	1.51E03	.23	1.12E+03	.17
I-BIOWAST	4.87E+03	.55	3.46E+03	.36	4.24E+03	.65	3.14E+03	.48
I+BIOWAST	4.87E+03	.55	3.46E+03	.36	4.24E+03	.65	3.14E+03	.48
N-SSWASTE	3.17E+04	3.61	6.34E+03	.66	1.27E+04	1.93	1.27E+04	1.95
N-LOWASTE	1.81E+04	2.06	1.21E+04	1.25	1.81E+04	2.76	1.21E+04	1.85
L-NFRCOMP	6.48E+02	.07	1.04E+03	.11	6.22E+02	.09	5.77E+02	.09
L-DECONRS	7.35E+03	.84	1.22E+04	1.27	8.05E+03	1.23	7.35E+03	1.13
N-ISOPROD	5.20E+03	.59	0.	0.	0.	0.	0.	0.
N-HIGHACT	8.09E+02	.09	5.74E+02	.06	7.04E+02	.11	5.22E+02	.08
N-TRITIUM	2.65E+03	.30	2.09E+02	.02	2.09E+02	.03	4.18E+02	.06
N-SOURCES	5.78E+01	.01	4.10E+01	.00	5.04E+01	.01	3.73E+01	.01
N-TARGETS	4.16E+02	.05	2.95E+02	.03	3.62E+02	.06	2.68E+02	.04
TOTAL	8.78E+05		9.66E+05		6.56E+05		6.50E+05	

- The I-BIOWAST and I+BIOWAST stream volumes represent volumes prior to packaging for shipment. Estimated shipping volumes are 0.92 volume parts lime and/or absorbent material to one volume part waste (Ref. 29).

- The N-SSWASTE and L-LOWASTE waste stream volumes represent volumes shipped for disposal.

- The L-DECONRS stream volume is composed of "dewatered" ion exchange resins that are projected to be generated during postulated future routine LWR decontamination activities.

- The N-ISOPROD stream volume represents the waste volume as packaged for shipment. Each package is assumed to contain a small volume of liquid solidified in cement within a metal canister which is then packaged with trash in a 55-gallon drum.

- All other industrial waste stream volumes are assumed to be as shipped for disposal.

3.2 Radionuclide Concentrations

This section discusses the available information and the procedures used in estimating the radioactive concentrations of the waste streams projected to be generated between the years 1980 and 2000 for the untreated waste streams presented in Table D.5. Additional information can be found in Reference 5.

Low-level radioactive wastes contain a large number of naturally occurring and man-made radionuclides at the time they are produced. Many of these radionuclides are very short lived and are not a long-term radiological concern. Other isotopes with half lives up to a few years may reach the disposal site but decay to insignificant levels shortly thereafter.

Two criteria were used in selecting the radionuclides considered: (1) its half life must be more than a few years (five years was used as a general guide) and (2) it must be present in comparatively significant quantities in LLW. The biological toxicities of radionuclides were also considered. Radionuclides that will be considered in this appendix are presented in Table D.10.

The sources of data on the concentrations of the radionuclides listed in Table D.10 include:

- computer-assisted calculations (Refs. 18-20);
- surveys of waste generators (Refs. 6-8, 21);
- disposal site records (Refs. 5, 14); and
- radiochemical analyses (Refs. 24-28).

Data from these sources suffer several limitations. Nonetheless, NRC staff believe that the data is generally conservative and is sufficiently accurate to make decisions regarding performance objectives and technical criteria for LLW management and disposal.

Table D.10 Radionuclides Considered in Waste Streams

Isotopes	Half Life (Years)	Principal Means of Production
H-3	12.3	Fission Li-6 (n, α)
C-14	5730	N-14 (n, p)
Fe-55	2.60	Fe-54 (n, γ)
Co-60	5.26	Co-59 (n, γ)
Ni-59	80,000	Ni-58 (n, γ)
Ni-63	92	Ni-62 (n, γ)
Sr-90	28.1	Fission
Nb-94	20,000	Nb-93 (n, γ)
Tc-99	2.12×10^5	Fission; Mo-98 (n, γ), Mo-99 (β^-)
I-129	1.17×10^7	Fission
Cs-135	3.0×10^6	Fission; daughter Xe-135
Cs-137	30.0	Fission
U-235	7.1×10^8	Natural
U-238	4.51×10^9	Natural
Np-237	2.14×10^6	U-238 (n, 2n), U-237 (β^-)
Pu-238	86.4	Np-237 (n, γ), Np-238 (β^-); daughter Cm-242
Pu-239	24,400	U-238 (n, γ), U-238 (β^-), Np-239 (β^-)
Pu-240	6,580	Multiple n-capture
Pu-241	13.2	Multiple n-capture
Pu-242	2.79×10^5	Muitiple n-capture; daughter Am-242
Am-241	458	Daughter Pu-241
Am-243	7950	Multiple n-capture
Cm-243	32	Multiple n-capture
Cm-244	17.6	Multiple n-capture

For example, computer calculations, which are often employed in predicting the radioactivity of wastes generated by "burn-up" of nuclear fuels, are based on fuel compositions, consumption (burn-up) rates, and elemental compositions of neutron-irradiated materials. While such calculations can be reasonably accurate, they are not as well-suited to determining the range of radioactivity concentrations produced by variations of operating conditions at a given reactor nor to representing wastes generated by typical reactors for purposes of analyzing disposal impacts.

A common limitation of obtaining concentrations of individual radionuclides obtained in surveys and from disposal facility radioactive shipment records is that they are frequently derived by application of predetermined distributions to the total gross beta/gamma activities obtained during screening measurements made at the time the wastes are shipped for disposal. These measurements are usually made with relatively unsophisticated instruments and are generally conservative since they include the activities contributed by very short-lived radionuclides.

The concentrations of several of the radionuclides listed in Table D-10 have been measured in samples of LWR process wastes (Refs. 22-25). These samples include those taken from smaller and older reactors, as well as those taken from reactors with a history of fuel failure problems, and are thus believed to be conservative with respect to future LWR wastes. Since radioactive concentrations vary with a reactor's operational cycle (fluctuation in power level, shutdowns and refueling), a larger number of samples would be useful to more accurately determine average concentrations.

Furthermore, the sensitivities (minimum detection limits) of the analytical procedures for the radionuclides of interest are not identical but vary with the type and energy of the radiation and with the presence of chemical and radiochemical interferences.

An additional point to be considered in using currently available radionuclide concentrations in the various waste streams is that the processes generating these wastes and the controls on these processes are likely to change. It is probable that the future distribution of radioisotopes will be away from fission products (e.g., Cs, Sr) and toward corrosion products due to improved fuel cladding properties.

The approach developed to estimate radionuclide concentrations in LLW to the year 2000 seeks to minimize the limitations of the available data through use of averaging procedures that reflect the quantity and quality of the available data. A discussion of the methodologies used to arrive at these estimates is presented in the following sections. The details of the calculations as well as a complete data compilation are contained in NUREG/CR-1759 (Ref. 5). The estimated radioactive concentrations for the untreated waste streams given in Table D.5 are presented in Tables D.11 through D.14.

3.2.1 Central Station Nuclear Power Plants

The LWR process waste streams (all waste streams except trash, core components, and decontamination wastes) are the best characterized of all the LLW streams.

Table D.11 Group 1 - Untreated Isotopic Concentrations (Ci/m^3)

TOTAL	P-IXRESIN 3.36E-02	P-CONCLIQ 1.09E-01	P-FSLUDGE 1.06E+00	P-FCARTRG 1.86+00	B-IXRESIN 4.63E+00	B-CONCLIQ 2.77E-01	B-FSLUDGE 5.24E+00
H-3	2.66E-03	3.45E-03	2.59E-03	1.15E-03	1.92E-02	6.24E-04	1.26E-02
C-14	9.74E-05	1.27E-04	9.55E-05	4.25E-05	1.19E-03	3.89E-05	7.78E-04
FE-55	2.34E-03	2.27E-02	3.10E-01	5.55E-01	9.48E-01	7.60E-02	1.44E+00
NI-59	2.79E-06	2.71E-05	3.71E-04	6.60E-04	9.80E-04	7.85E-05	1.49E-03
CO-60	4.53E-03	4.40E-02	6.00E-01	1.07E+00	1.59E+00	1.27E-01	2.41E+00
NI-63	8.61E-04	8.36E-03	1.14E-01	2.04E-01	2.15E-02	1.72E-03	3.25E-02
NB-94	8.84E-08	8.58E-07	1.17E-05	2.09E-05	3.09E-05	2.48E-06	4.70E-05
SR-90	1.94E-04	2.52E-04	1.89E-04	8.40E-05	3.64E-03	1.18E-03	2.37E-03
TC-99	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
I-129	2.44E-06	3.16E-06	2.37E-06	1.06E-06	2.04E-04	6.65E-06	1.33E-04
CS-135	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
CS-137	2.19E-02	2.85E-02	2.14E-02	9.54E-03	2.04E+00	6.65E-02	1.33E+00
U-235	4.71E-08	6.15E-08	1.46E-07	3.64E-07	5.33E-08	3.44E-08	3.32E-07
U-238	3.71E-07	4.84E-07	1.15E-06	2.87E-06	4.20E-07	2.71E-07	2.61E-06
NP-237	9.06E-12	1.18E-11	2.81E-11	7.02E-11	1.02E-11	6.61E-12	6.38E-11
PU-238	2.60E-05	5.12E-05	4.76E-05	2.51E-04	8.34E-05	1.99E-04	4.66E-04
PU-239/240	1.82E-05	3.31E-05	1.55E-04	3.80E-04	5.34E-05	9.43E-05	2.36E-04
PU-241	7.94E-04	1.44E-03	6.75E-03	1.66E-02	2.60E-03	4.60E-03	1.15E-02
PU-242	3.99E-08	7.25E-08	3.39E-07	8.34E-07	1.17E-07	2.06E-07	5.18E-07
AM-241	1.87E-05	2.99E-05	2.64E-04	1.64E-04	2.32E-05	1.20E-04	1.56E-04
AM-243	1.26E-06	2.02E-06	1.78E-05	1.10E-05	1.57E-06	8.10E-06	1.05E-05
CM-243	9.92E-09	1.17E-08	3.10E-07	1.93E-07	2.70E-08	2.59E-07	2.97E-07
CM-244	1.38E-05	1.92E-05	1.77E-04	1.10E-04	1.82E-05	2.05E-04	2.24E-04

Table D.12 - Group 2 Untreated Isotopic Concentrations (Ci/m³)

TOTAL	P-COTRASH 2.28E-02	P-NCTRASH 5.25E-01	B-COTRASH 2.35E-02	B-NCTRASH 3.79E+00	F-COTRASH 5.58E-06	F-NCTRASH 5.33E-06	I-COTRASH 1.13E-01	N-SSTRASH 1.12E-05	N-LOTRASH 3.53E-02
H-3	3.04E-04	6.99E-03	6.75E-05	1.09E-02	0.	0.	9.13E-02	0.	2.85E-02
C-14	1.12E-05	2.57E-04	4.17E-06	6.73E-04	0.	0.	5.26E-03	0.	1.64E-03
FE-55	5.97E-03	1.37E-01	6.01E-03	9.69E-01	0.	0.	0.	0.	0.
NI-59	7.11E-06	1.64E-04	6.21E-06	1.00E-03	0.	0.	0.	0.	0.
CO-60	1.15E-02	2.65E-01	1.01E-02	1.62E+00	0.	0.	1.04E-02	0.	3.25E-03
NI-63	2.19E-03	5.05E-02	1.36E-04	2.19E-02	0.	0.	0.	0.	0.
NB-94	2.25E-07	5.18E-06	1.96E-07	3.16E-05	0.	0.	0.	0.	0.
SR-90	2.22E-05	5.11E-04	1.27E-05	2.05E-03	0.	0.	1.45E-03	0.	4.53E-04
TC-99	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	3.39E-09	0.	1.06E-09
I-129	2.78E-07	6.41E-06	7.14E-07	1.15E-04	0.	0.	0.	0.	0.
CS-135	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	0.	0.	0.
CS-137	2.51E-03	5.78E-02	7.14E-03	1.15E+00	0.	0.	4.56E-03	0.	1.42E-03
U-235	7.89E-09	1.82E-07	1.22E-09	1.97E-07	1.18E-06	1.13E-06	0.	2.36E-06	0.
U-238	6.22E-08	1.43E-06	9.60E-09	1.55E-06	4.40E-06	4.20E-06	0.	8.80E-06	0.
NP-237	1.52E-12	3.49E-11	2.35E-13	3.78E-11	0.	0.	0.	0.	0.
PU-238	5.97E-06	1.38E-04	2.30E-06	3.71E-04	0.	0.	0.	0.	0.
PU-239/240	5.53E-06	1.27E-04	1.16E-06	1.86E-04	0.	0.	0.	0.	0.
PU-241	2.41E-04	5.55E-03	5.63E-05	9.08E-03	0.	0.	0.	0.	0.
PU-242	1.21E-08	2.79E-07	2.53E-09	4.08E-07	0.	0.	0.	0.	0.
AM-241	3.96E-06	9.12E-05	9.67E-07	1.56E-04	0.	0.	4.82E-06	0.	1.51E-06
AM-243	2.67E-07	6.15E-06	6.52E-08	1.05E-05	0.	0.	0.	0.	0.
CM-243	2.74E-09	6.30E-08	1.93E-09	3.12E-07	0.	0.	0.	0.	0.
CM-244	2.61E-06	6.00E-05	1.49E-06	2.41E-04	0.	0.	0.	0.	0.

Table D.13 Group 3 - Untreated Isotopic Concentrations (Ci/m³)

	F-PROCESS	U-PROCESS	I-LQSCNVL	I-ABSLIQD	I-BIOWAST	N-SSWASTE	N-LOWASTE
TOTAL	1.08E-04	3.80E-04	9.60E-03	1.99E-01	2.06E-01	2.17E-04	2.11E-02
H-3	0.	0.	5.01E-03	1.42E-01	1.75E-01	0.	1.63E-02
C-14	0.	0.	2.51E-04	8.16E-03	1.01E-02	0.	9.36E-04
FE-55	0.	0.	0.	0.	0.	0.	0.
NI-59	0.	0.	0.	0.	0.	0.	0.
CO-60	0.	0.	0.	3.12E-02	3.99E-03	0.	1.47E-03
NI-63	0.	0.	0.	0.	0.	0.	0.
NB-94	0.	0.	0.	0.	0.	0.	0.
SR-90	0.	0.	4.34E-03	4.34E-03	8.33E-03	0.	1.31E-03
TC-99	0.	0.	0.	1.02E-08	6.51E-09	0.	7.76E-10
I-129	0.	0.	0.	0.	0.	0.	0.
Cs-135	0.	0.	0.	0.	0.	0.	0.
CS-137	0.	0.	0.	1.37E-02	8.76E-03	0.	1.04E-03
U-235	2.30E-05	1.65E-05	0.	0.	0.	4.60E-05	0.
U-238	8.54E-05	3.64E-04	0.	0.	0.	1.71E-04	0.
NP-237	0.	0.	0.	0.	0.	0.	0.
PU-238	0.	0.	0.	0.	0.	0.	0.
PU-239/240	0.	0.	0.	0.	0.	0.	0.
PU-241	0.	0.	0.	0.	0.	0.	0.
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	0.	0.	0.	0.	0.	0.	0.
AM-243	0.	0.	0.	0.	0.	0.	0.
CM-243	0.	0.	0.	0.	0.	0.	0.
CM-244	0.	0.	0.	0.	0.	0.	0.

Table D.14 Group 4 - Untreated Isotopic Concentrations (Ci/m^3)

TOTAL	L-NFRCOMP 4.04E+03	L-DECONRS 1.56E+02	N-ISOPROD 1.50E+01	N-HIGHACT 2.10E+02	N-TRITIUM 2.33E+03	N-SOURCES 5.76E+03	N-TARGETS 8.04E+01
H-3	0.	1.08E-02	4.20E-02	0.	2.33E+03	8.63E+02	8.04E+01
C-14	2.59E-01	5.13E-04	4.51E-05	1.32E-02	0.	5.76E+01	0.
FE-55	2.23E+03	4.05E+01	0.	1.15E+02	0.	0.	0.
NI-59	1.40E+00	4.49E-02	0.	6.56E-02	0.	0.	0.
CO-60	1.60E+03	7.28E+01	0.	8.48E+01	0.	1.73E+03	0.
NI-63	2.09E+02	3.69E+00	0.	1.06E+01	0.	2.30E+02	0.
NB-94	8.19E-03	1.42E-03	0.	4.47E-04	0.	0.	0.
SR-90	0.	4.28E-02	6.27E+00	0.	0.	1.15E+03	0.
TC-99	0.	1.20E-05	3.27E-04	0.	0.	0.	0.
I-129	0.	3.34E-05	2.72E-06	0.	0.	0.	0.
CS-135	0.	1.20E-05	3.27E-04	0.	0.	0.	0.
CS-137	0.	3.18E-01	8.73E+00	0.	0.	1.15E+03	0.
U-235	0.	6.84E-05	1.02E-05	0.	0.	0.	0.
U-238	0.	5.40E-04	3.81E-05	0.	0.	0.	0.
NP-237	0.	1.32E-08	5.33E-13	0.	0.	0.	0.
PU-238	0.	1.34E+00	1.97E-04	0.	0.	0.	0.
PU-239/240	0.	1.77E+00	5.55E-05	0.	0.	0.	0.
PU-241	0.	3.55E+01	7.10E-03	0.	0.	0.	0.
PU-242	0.	3.87E-03	9.57E-08	0.	0.	0.	0.
AM-241	0.	5.29E-03	1.10E-05	0.	0.	5.76E+02	0.
AM-243	0.	3.59E-04	1.25E-06	0.	0.	0.	0.
CM-243	0.	3.46E-04	1.65E-04	0.	0.	0.	0.
CM-244	0.	3.27E-03	2.88E-07	0.	0.	0.	0.

This situation allows the 23 radionuclides (Pu-239 and Pu-240 cannot be distinguished by radiochemical methods and are considered here as a single isotope) listed in Table D.10 to be divided into three groups: (1) radionuclides for which a representative set of data is available and for which the number of measurements are believed to be sufficient to allow averaging; (2) radionuclides for which a representative set of data is available but for which the number of measurements are believed to be insufficient to allow direct averaging; and (3) radionuclides that have not been measured or for which there is some concern regarding the representativeness of the existing data.

Radionuclides in the first group include Co-60, Cs-137, U-238, Pu-238, Pu-239/240, Am-241 and Cm-244. These radionuclides are hereafter referred to as the "basic" isotopes. (The comparatively short-lived isotope Cm-242 is also included as a basic isotope and used to estimate the concentrations of other curium isotopes in some waste streams as described below.) The estimated concentrations of these basic isotopes were calculated as the geometric means of the measured concentrations in each waste stream with the exception of Cm-243 and Cm-244 in PWR filter sludge (see below).

The geometric average is calculated as the (n)th root of the product of the (n) data points. The use of geometric means rather than arithmetic means allows representative estimates to be made from sets of data that contain a few concentrations that are several orders of magnitude greater than the majority in the set and that would dominate the average if arithmetic means were used.

The difference in results obtained from arithmetic and geometric means is readily illustrated by considering a set of data consisting of 20 values of 1 and one value of 1000. The arithmetic average of these 21 values is 48.6 and the geometric average is 1.39. The geometric average is clearly more representative of the typical value. Variations of this magnitude have been observed in radionuclide concentration of waste streams at several LWRs (Ref. 22-24). Geometric averages are therefore a compromise between the impracticality of investigating the conditions under which each sample was collected and the use of uncharacteristically high arithmetic means.

The second and third groups of radionuclides were "scaled" to the above list of basic radionuclides. The scaled radionuclides and the basic radionuclides are given in Table D.15.

The second group of radionuclides--those for which the number of measurements is considered to be insufficient to allow direct geometric averaging--consists of H-3, C-14, Fe-55, Ni-63, Sr-90, I-129, Pu-241, and Pu-242. The concentrations of these radionuclides were calculated by "scaling" to the concentration of an appropriate basic isotope. These radionuclides were paired on the basis of a common source and/or method of production. For example, activated corrosion products (Fe-55 and Ni-63) are scaled to Co-60, which is also an activated corrosion product; fission products Sr-90, I-129, and H-3 (H-3 is also produced by activation) are scaled to Cs-137, which is also a fission product; and Pu-241 and Pu-242 are scaled to Pu-239/240, the nuclides from which they originate through multiple neutron capture. Carbon-14 is rather difficult to categorize; it was scaled to Cs-137.

Table D.15 Basic and Scaled Radionuclides for LWR Process Waste Streams

Basic Isotope	Scaled Isotopes
Co-60	Fe-55, Ni-59, Ni-63, Nb-94
Cs-137	H-3, C-14, Sr-90 Tc-99, I-129, Cs-135
U-238	U-235, Np-237
Pu-238	--
Pu-239/24	Pu-241, Pu-242
Am-241	Am-243, Cm-242*
Cm-242	Cm-243, Cm-242*
Cm-244	--

*Only for the P-FSLUDGE waste stream.

Scaling was accomplished using data for samples that were analyzed for both the radionuclide to be scaled and the appropriate basic isotope. The ratio of the concentration of the radionuclide to be scaled to that of the basic isotope was calculated for each data pair. A "scaling factor" for each of the radionuclides in this second group was then calculated as the geometric average of each set of ratios. (The scaling factors were calculated by reactor type only (BWRs and PWRs), rather than by reactor type and by waste stream like the basic radionuclides.) The computed scaling factors were then applied to the geometric averages of basic radionuclides to obtain the estimated concentrations of the scaled radionuclides given in Table D.11. A special scaling factor was calculated by this procedure for Cm-242 in PWR filter sludge using Cm-242/Am-241 data pairs for PWR cartridge filters.

The third group of radionuclides consists of Ni-59, Nb-94, Tc-99, Cs-135, U-235, Np-237, Am-243, and Cm-243. For these radionuclides, concentrations obtained from computer calculations (Ref. 31), (Ni-59 and Nb-94) or from other information (Ref. 27), were ratioed to the mean concentrations of the basic isotopes to obtain scaling factors. In the case of U-235, an average enrichment of 2% was assumed, and was then used as described above to estimate concentrations from U-238 concentrations in each stream. (A 2% enrichment was assumed to account for burnup during reactor operation.)

The radioactive concentrations of BWR and PWR trash were estimated by assuming that the radioactivity of the trash is proportional to the activity of the BWR and PWR process waste streams, respectively. Accordingly, the estimated concentrations (Table D.12) and the as-generated volumes of LWR process wastes were used to calculate normalized isotopic distributions from the volume-weighted average concentration of each radionuclide in BWR and PWR process wastes. These distributions were then applied to the average gross activities estimated to be contained in PWR compactible and noncompactible trash (0.0228 Ci/m^3 and 0.525 Ci/m^3 and of BWR compactible and noncompactible trash, (0.0235 Ci/m^3 and 3.79 Ci/m^3) (Ref. 6, 14). The resultant concentrations, presented in Table D.12, are conservative since they are based on total activities that include the contributions of short-lived radionuclides.

The radionuclide concentrations of LWR nonfuel reactor components (L-NFRCOMP), are given in Table D.14 and were estimated by assuming that the total activity is due to neutron activation of steel components. A normalized distribution calculated from ORIGEN calculations of the radioactivity of highly activated metals (Ref. 31) was applied to a total estimated gross radioactivity of 4040 Ci/m^3 (Ref. 14).

Given the uncertainties involved with projecting characteristics of future LWR decontamination wastes, it is difficult to estimate radionuclide concentrations of these wastes. For the purposes of this appendix, however, the radionuclide concentrations of LWR decontamination wastes, given in Table D.14, were calculated from available data on radionuclide concentrations in crud deposits in LWR cooling systems (Refs. 22-24, 26). Scaling procedures similar to those used for LWR process wastes were used, although no differentiation was made between BWR and PWR wastes. The basic crud isotopes are Co-60, Cs-137, U-238, Pu-238, Pu-239/240, Am-241, Cm-242 and Cm-244. Sufficient data is available for Sr-90 and Pu-241 in LWR crud to allow calculations of scaling factors as geometric means of ratios as described for LWR process wastes. Results of the analysis of a single sample (Ref. 28) were used to scale Fe-55 and Ni-63 to Co-60. Scaling factors for the remaining radionuclides were calculated as geometric means of the corresponding scaling factors for BWR and PWR process wastes. After applying these scaling factors to the concentrations of the basic crud isotopes, the concentrations of all 23 radionuclides were normalized and applied to a total estimated activity (Ref. 5) of 156 Ci/m^3 to obtain the concentrations given in Table D.14.

Use of this procedure to estimate radionuclide concentrations in the L-DECONRS stream results in estimated transuranic concentrations in considerable excess of 10 nCi/gm. Thus, the L-DECONRS stream as postulated would not be acceptable for disposal at existing LLW disposal facilities. Use of crud scrapings to estimate concentrations is believed to be conservative and perhaps overly conservative, since data from the Dresden 1 decontamination operations indicates that the generated decontamination waste will have transuranic concentrations less than 10 nCi/gm (Ref. 15). Despite this, however, NRC staff believe that the low Dresden 1 transuranic concentrations may not be indicative of all future decontamination operations. As discussed in Section 3.1.1, the characteristics of future decontamination wastes are uncertain and may be a function of a number of plant-specific conditions. Some of these include the type and size of the reactor, the operating history of the plant, the design of the plant and liquid clean-up and processing systems, the chemistry of the primary coolant, the type of decontamination operation performed, and the length of time between decontamination operations. Thus, it would appear to be appropriate to determine radionuclide concentrations in future full-scale decontamination waste streams on a plant-specific basis.

For the purposes of this environmental impact statement, however, it is useful to use crud scraping data to estimate radionuclide concentrations in potential future LWR decontamination waste streams. Such concentrations are believed to be bounding and furthermore can be used to analyze disposal impacts from a relatively small volume of transuranic-contaminated waste.

3.2.2 Other Nuclear Fuel Cycle Facilities

These waste streams consist of process wastes and trash from uranium conversion and fuel fabrication plants. Little data is available on the radionuclide concentrations of these streams, although U-235 and U-238 were the only radionuclides identified as being included in these waste streams.

Radionuclide concentrations in fuel fabrication wastes were determined based on data obtained from radioactive waste shipment records (RSRs) of waste shipped to the Maxey Flats disposal facility. The masses of special nuclear material reported in the RSRs were used to calculate concentrations of U-235 in each waste stream. Concentrations of U-238 were then calculated by assuming that the uranium in these wastes contained 4% by weight U-235. The estimated concentration of fuel fabrication wastes are given in Tables D.12 and D.13.

The concentrations of U-235 and U-238 in uranium conversion process waste were calculated from data given in Reference 28. It was assumed that the uranium was unenriched (0.711 percent U-235 by weight). Estimated concentrations are given in Table D.13.

3.2.3 Institutional Facilities

The most complete set of data available for institutional waste volumes and radionuclides were obtained during surveys of these generators conducted by the University of Maryland. However, in the published form (Refs. 7, 8), the data is not suitable for estimating the radionuclide concentrations in each waste stream. For the purposes of this appendix (Ref. 5), the survey data was reformatted and additional analysis performed (Refs. 21, 29). The results of this analysis, presented in Table D.16, combined with the estimated volumes of each waste stream (Refs. 7, 8, 14), were used to estimate the radionuclide concentrations in institutional waste streams given in Tables D.12 and D.13. The methodology employed is briefly described below.

The data presented in Table D.16 was compiled for the survey data base by summing the total reported activity of each radionuclide shipped to disposal facilities, as well as the total volume of all wastes reported to contain each radionuclide. The form of the data did not allow these summations to be made for individual waste streams, but did allow determination of whether a

Table D.16 Radionuclide Distribution in Institutional Wastes in 1977

Nuclide	Waste Fraction* (ft^3)	Dry Solids	Liquid Scint. Vials	Absorbed Liquids	Biological Wastes	Total Activity Shipped (mCi)
H-3	159,697	X	X	X	X	236,151
C-14	158,060	X	X	X	X	13,488
Na-22	96,539	X		X	X	207
P-32	148,684	X	X	X	X	24,729
P-33	15,020	X	X	X	X	18
S-35	140,729	X	X	X	X	12,649
Cl-36	45,974	X	X	X	X	14
Ca-45	135,238	X	X	X	X	2,041
Sc-46	26,962	X		X	X	128
Cr-51	146,634	X	X	X	X	9,918
Mn-54	14,903	X		X	X	8
Fe-59	37,958	X		X	X	268
Co-57	37,600	X		X	X	212
Co-60	22,979	X		X	X	3,341
Ga-67	34,730	X		X	X	2,319
Se-75	79,046	X	X	X	X	948
Rb-86	64,239	X	X	X	X	226
Sr-85	42,931	X		X	X	309
Sr-90	13,997	X	X	X	X	573
Nb-95	10,976	X		X	X	136
Mo-99	13,674	X				15,080
Tc-99m	38,348	X		X	X	19,903
In-111	15,175	X		X	X	179
Sn-113	15,175	X		X	X	194
I-125	148,442	X	X	X	X	47,882
I-131	69,693	X		X		6,620
Xe-133	6,234	X				1,356
Cs-137	15,086	X		X	X	1,101
Ce-141	32,856	X		X	X	175
Yb-169	8,490	X		X	X	315
Tl-201	15,667	X		X	X	565
Others	116,895	X	X	X	X	3,760

*Total volume of shipped waste reported to contain a given isotope. Total volume of shipped waste was 185,160 ft^3.

Source: Reference 21.

radionuclide was present in a given stream. (In Table D.16, an "X" indicates that an isotope was reported in the stream indicated.) The total activity of each radionuclide was then divided by the total volume of waste reported to contain that radionuclide to obtain initial radionuclide concentrations.

Radionuclide concentrations in each institutional waste stream were derived from the initial concentrations by consideration of: the as-shipped volume of the waste stream relative to the total volume of all four streams (42.3% trash, 38.5% liquid scintillation vials, 10% absorbed liquids and 9% biowaste) (Ref. 14); the presence or absence of a radionuclide in the stream; and the fraction of the as-shipped volume which consists of radioactive waste. The following assumptions were then applied.

- One-half the volume of liquid scintillation vials is occupied by scintillation fluids; one-half the volume of absorbed liquids is scintillation fluids and one-half is aqueous liquids (Ref. 7).
- The tritium and C-14 activities of liquid scintillation fluids are 10 nCi/cm^3 and 5 nCi/cm^3, respectively (Refs. 7, 8).
- All Mo-99 and Tc-99m have decayed to Tc-99 prior to shipment.
- The activity of Co-60 in biowaste is one-fifth its activity in the other waste streams (Ref. 29).
- Institutions shipped 6230 m^3 of trash containing 30 mCi of Am-241 (Ref. 29).

The radionuclide concentrations in institutional wastes estimated by this procedure are given in Tables D.12 and D.13.

3.2.4 Industrial Facilities

The radionuclide concentrations of industrial wastes were estimated based upon a number of information sources available to NRC (Ref. 14). Radionuclide concentrations are presented in Tables D.12, D.13, and D.14. The details of the calculations can be found in Reference 5.

Medical isotope production (N-ISOPROD) wastes, which are assumed to consist of trash and solidified aqueous liquids, are considered as a single waste stream (see Section 2.5). The radionuclide concentrations of the N-ISOPROD stream are not well characterized. Data obtained from available disposal facility RSRs for the radionuclides of interest are limited to the combined Sr-90/Cs-137 radioactivity, grams of U-235, and waste volumes. In order to estimate the concentrations of the remaining radionuclides, the waste density was assumed to be 1.6 g/cm^3 and the total activity of alpha-emitting transuranic radionuclides was assumed to be 1 nCi/g. (Existing isotope production wastes have been measured to have transuranic concentrations less than 1 nCi/gm.) The radionuclides were then divided into three groups: (1) activation and fission products, (2) uranium, and (3) transuranium radionuclides. Information regarding the radionuclide distribution in spent fuel was used to obtain normalized distributions of activation and fission products and of transuranics (Ref. 5). These distributions were used with the combined activities of Sr-90 and Cs-137 obtained from the Maxey Flats data and the assumed activity of the alpha-emitting transuranics to calculate the radionuclide concentrations given in Table D.14.

Industrial high activity wastes (N-HIGHACT) consist of neutron irradiation capsules, activated components from research reactors, and other activated waste materials. The radionuclide concentrations of these wastes (Table D.14) were calculated using scaling factors developed for highly activated metals from decomissioning activities (Ref. 31).

The total radioactivity of industrial tritium manufacturing wastes N-TRITIUM, 2330 Ci/m^3, is assumed to be due to tritium (Ref. 14).

Estimation of the activity of sealed sources and foils (N-SOURCES) and the isotopic distribution of this activity is difficult since they are shipped for disposal infrequently and at irregular intervals. Scaling factors were assumed and applied based on several sources (Ref. 5).

Accelerator targets (N-TARGETS) consist of tritium absorbed on titanium foils. Since there is no indication that induced activities are present (Ref. 8), the total activity of 80.4 Ci/m^3 contained in this waste stream is assumed to be only tritium (Ref. 14).

The only radionuclides identified in source and special nuclear material wastes (N-SSWASTE) are U-235 and U-238. The wastes are generated primarily during processing of metals and compounds containing depleted uranium. The uranium isotopes are conservatively assumed to be present in the same ratio as in natural uranium; thus, 4.3% of the total activity is assumed to be due to U-235 and 95.6% due to U-238.

The types of materials comprising the industrial low activity waste stream (N-LOWASTE) are the industrial equivalents of institutional wastes--i.e., trash, liquid scintillation vials, absorbed liquids, and biowastes. As discussed in Section 2.5, these types of wastes are not sufficiently well-characterized to be considered as separate streams. It was therefore assumed that these industrial wastes have the same distribution of radionuclide concentrations as institutional wastes. Concentrations of individual radionuclides were then estimated using volume-weighted averaging analogous to that used for LWR trash.

4. WASTE PROCESSING OPTIONS

There are many processing technologies currently available that can be utilized to alter and/or improve the performance characteristics of radioactive waste forms. This section briefly considers several of these technologies and presents their estimated impacts on waste generators and/or disposal facility operators. The discussion in this section is obtained from the more detailed treatment provided in Reference 5. Additional information can be found in the references to this appendix.

In order to assess the comparative effects of the waste processing options considered in this appendix four impact measures are quantified in this section. These impact measures are occupational exposures, population exposures, costs, and energy use. Only incineration is assumed to result in potential significant population exposures as a result of processing. Other processes, including evaporation, compaction, solidification, and packaging, are assumed not to result in potentially significant additional population exposures to those.

Waste processing options are considered in three sections in this appendix. Section 4.1 addresses processes that result in a reduced volume of waste after processing. Section 4.2 addresses processes that result in an increased volume of waste after processing. Section 4.3 briefly discusses the possible use of high-integrity packages for containment of radionuclides during transportation and after disposal.

4.1 Volume Reduction

There are three basic processes that can be applied to waste streams that result in overall waste volume reduction: (1) physical processes such as compaction, (2) thermal processes such as evaporation, and (3) incineration and other related combustion processes. Each of these processes produces a concentrate stream and an effluent stream. The respective concentrate streams are compressed wastes concentrated liquids or crystals, and ash. The respective effluents displaced are air, vapor, and gas and vapor. The activity per unit volume of the concentrate stream is usually higher than that of the untreated waste with the possible exception of volatile nuclides such as tritium, carbon, and iodine that may be entrained as vapor and/or combustion products in the effluent stream.

The volume reduction factor (VRF) is defined in this appendix as the ratio of the waste volume that is input to the process (untreated volume) to that of the concentrated (treated) waste volume.

4.1.1 Compaction

Compaction is an often-used method--particularly at nuclear fuel cycle facilities--of reducing the volume of waste streams containing compressible material such as paper, plastic, glass, wood, and light-gauge metal. Most of the volume reduction is attained by compressing the waste to reduce its void volume. The term compactor is usually applied to hydraulic or mechanical rams that compress wastes into 55-gallon steel drums. The drums are then used as disposal containers. Typical hydraulic rams generate 20,000 to 30,000 pounds of force, and are fitted with shrouds and simple air filtration systems to minimize release of airborne radioactivity.

Most compactors now in use can achieve average volume reduction factors of about two. Newer compactors, which place a metal inner sleeve inside the drum during compaction, are capable of a volume reduction factor of about four (Ref. 10). Industrial hydraulic presses similar to those used to crush automobiles may be useful for compacting heavier gauge metal items such as pipes, tools, cans, drums, and scaffolding.

In this appendix, three types of compactors are considered: compactor/shredders that can be utilized to achieve volume reduction factors of around 1.5 to 2; improved compactor/shredders that can achieve volume reduction factors of about 4; and industrial hydraulic presses that are assumed to be capable of achieving volume reduction factors of about 6. In the analysis, the compactor/ shredders and improved compactor/shredders are assumed to be operable as an option by any facility capable of implementing its own processing system (fuel cycle facilities and large institutional and industrial facilities). Industrial hydraulic presses, however, are assumed to be operable only at a centralized waste processing facility.

The waste streams to which these compaction techniques are applied, and their unit impact measures, are summarized in Table D.17.

Table D.17 Compaction Techniques and Impacts

Compaction Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Reduction Factor
Compactor/shredder	$ 335	15	4.6	P-COTRASH	2.0
				B-COTRASH	2.0
				F-COTRASH	1.5
				I-COTRASH	2.0
				N-SSTRASH	1.5
				N-LOTRASH	2.0
				I-LQSCNVL	1.28
Improved compactor/ shredder	$ 503	15	4.6	I+COTRASH	4.0
				N+SSTRASH	3.0
				N+LOTRASH	4.0
Industrial hydraulic press	$1006	15	4.6	P-NCTRASH	6.0
				B-NCTRASH	6.0
				F-NCTRASH	6.0

*Cost and man-hours are given in unit volume of input volume (untreated) waste. Impact measures were developed based upon data obtained from Reference 32.

4.1.2 Evaporation

Evaporators concentrate liquid wastes by heating them to vaporize the volatile components. The vaporized water generally contains greatly reduced quantities of dissolved solids, suspended solids, and radioactivity relative to those found in the input waste stream. In the nuclear industry the vaporized water is normally condensed and collected, and then either discharged or recycled after testing to determine whether the condensate requires additional treatment. The concentrated solution (bottoms) left in the evaporator retains virtually all of the solids and radioactivity and is solidified and shipped to a disposal facility.

Evaporators can be categorized according to their methods of heat transfer (Ref. 33). Natural circulation evaporators use convection as the means of heat transfer. Forced circulation evaporators (Figure D.4) use pumps to improve the flow of liquid over the heating surfaces. Fluidized-bed dryers produce dry salts by injecting atomized waste liquids onto a hot bed of inert granules that is suspended (fluidized) in a stream of hot air (Refs. 34, 35). The liquids flash-evaporate on contact with the hot bed, leaving behind a residue of dry solids. The inert carrier process (Ref. 36) uses a hot bath of inert fluid recirculating at high velocities as the heat exchanger. Solidification in bitumen can also be considered as a form of evaporation. The ideal evaporator produces a condensate that is free of radioactivity while attaining the maximum volume reduction of the input waste liquid.

In this appendix, evaporator/crystallizers (Ref. 33) (Figure D.5) are assumed to be utilized as an option to further concentrate the already concentrated liquid waste streams of LWRs. For the reference representative evaporator/crystallizer, the volume reduction factors assumed in this appendix are 6.0 and 2.4 for the P-CONCLIQ and B-CONCLIQ streams, respectively. The impact measures are $690, 4.42 man-hours, and 56.3 gallons of fuel per m^3 of untreated input waste liquid (Ref. 32).

4.1.3 Incineration

Incinerators and related devices decompose combustible waste materials by thermal oxidation. Combustion or incineration involves complete oxidation of wastes by burning in an excess of oxygen (air). Pyrolysis involves partial oxidation in an oxygen-deficient atmosphere. Oxidation can also be accomplished by introducing combustible wastes and air into a bath of molten salt. Alternatively, acid digesters oxidize wastes in a hot mixture of concentrated nitric and sulfuric acids.

The various types of incinerators, pyrolyzers, and other such devices currently used or being developed for volume reduction of radioactive waste are too numerous (Ref. 32) to be considered here individually. Two reference types of representative incinerators have been selected for discussion in this appendix: pathological incinerators and fluidized bed incinerators. The reference pathological incinerator is considered for optional use by large institutional waste generators such as hospitals and biomedical research facilities. The reference fluidized bed incinerator is considered for optional use by fuel cycle waste generators or by operators of a potential regional waste processing facility incinerating wastes from small waste generators. The waste streams treated with these two types of incinerators and the resultant unit impact measures are presented in Table D.18.

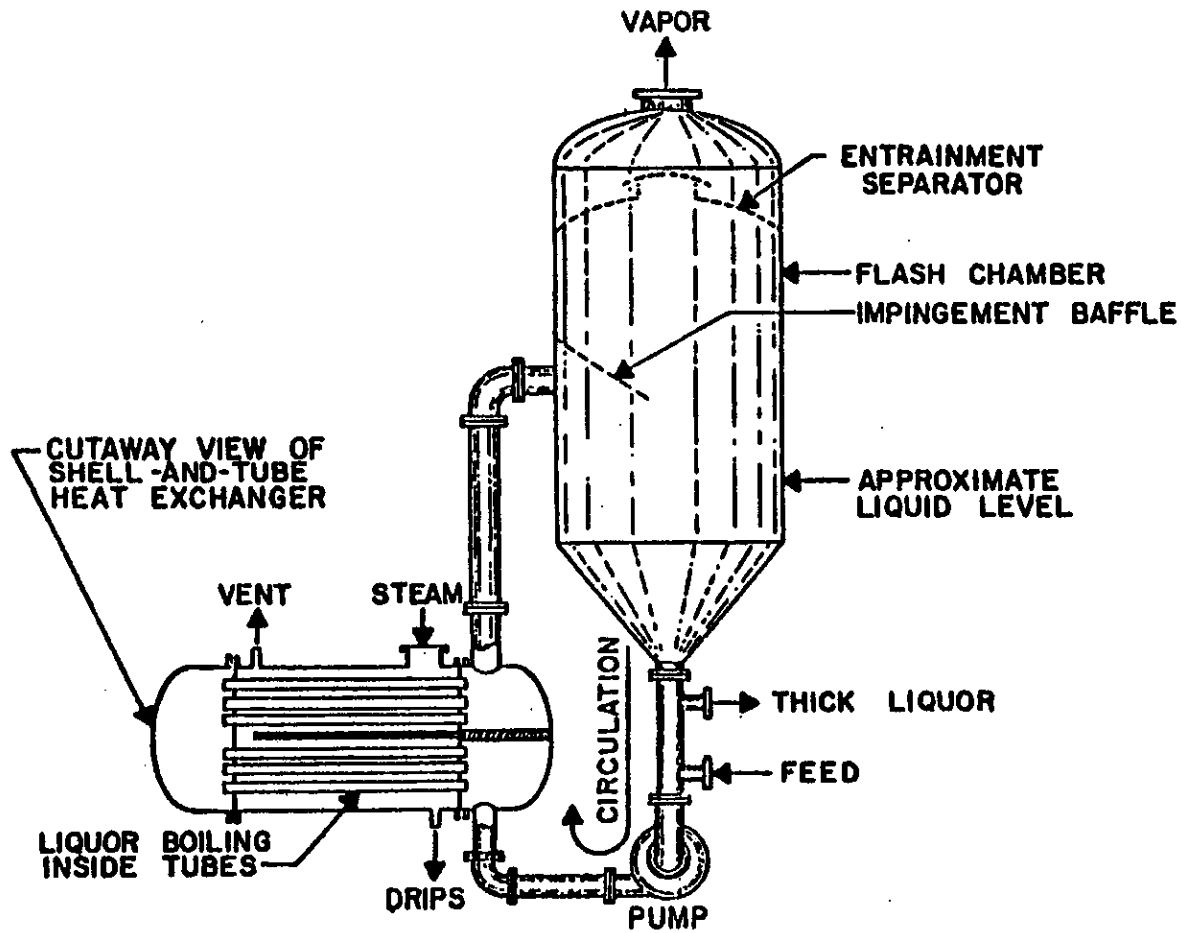


Figure D.4 Forced-Circulation Evaporator With An External Horizontal, Submerged-Tube, Two-Pass Heater

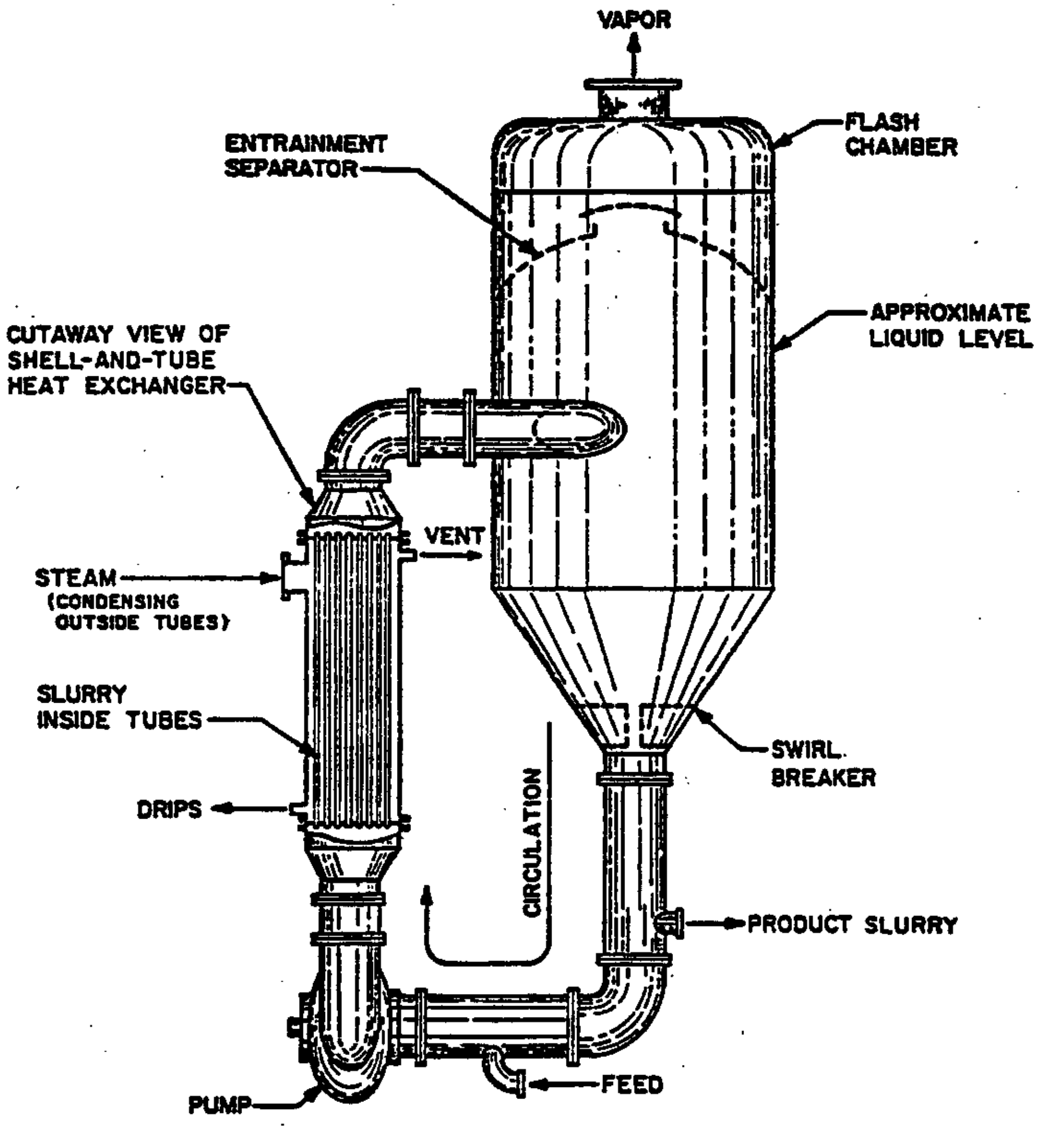


Figure D.5 Evaporator/Crystallizer

Table D.18 Incineration Techniques and Impacts

Incineration Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Reduction Factor
Pathological incinerator	$2,060	8	116	I-COTRASH	20.0
				N-SSTRASH	10.0
				N-LOTRASH	20.0
				I-LQSCNVL	4.52
				I-ABSLIQD	100.0
				I-BIOWAST	15.0
Fluidized bed incinerator (at facilities)	$1,938	6.12	129	P-IXRESIN	18.0
				P-CONCLIQ	8.0
				P-FSLUDGE	5.0
				B-IXRESIN	18.0
				B-CONCLIQ	6.4
				B-FSLUDGE	5.0
				P-COTRASH	80.0
				B-COTRASH	80.0
				F-COTRASH	40.0
				L-DECONRS	18.0
Fluidized bed incinerator (at regional processing center)	$1,039	5.35	72	I+COTRASH	80.0
				N+SSTRASH	40.0
				N+LOTRASH	80.0

*Cost and man-hours are given in unit volume of untreated waste. Impact measures are based upon data obtained from References 32, 37, and 39.

Pathological incinerators are typically multiple-chamber, hot refractory hearth incinerators (Figure D.6) and are normally operated with less sophisticated off-gas treatment systems (Ref. 37). Airborne releases are principally controlled through control of the rate of input feed. They are designed primarily for the incineration of animal carcasses and operate at approximately 900 to 1000°C. Pathological incinerators may also be used by institutional waste generators for volume reduction of other biowastes, scintillation fluids, organic liquids, and trash. Aqueous liquids can also be evaporated on the refractory hearth.

Fluidized bed incinerators (Figure D.7) operate by injecting combustible wastes into a hot bed of inert granules fluidized by a stream of hot gas. They operate on the same principle as fluidized bed dryers or calciners which have been used

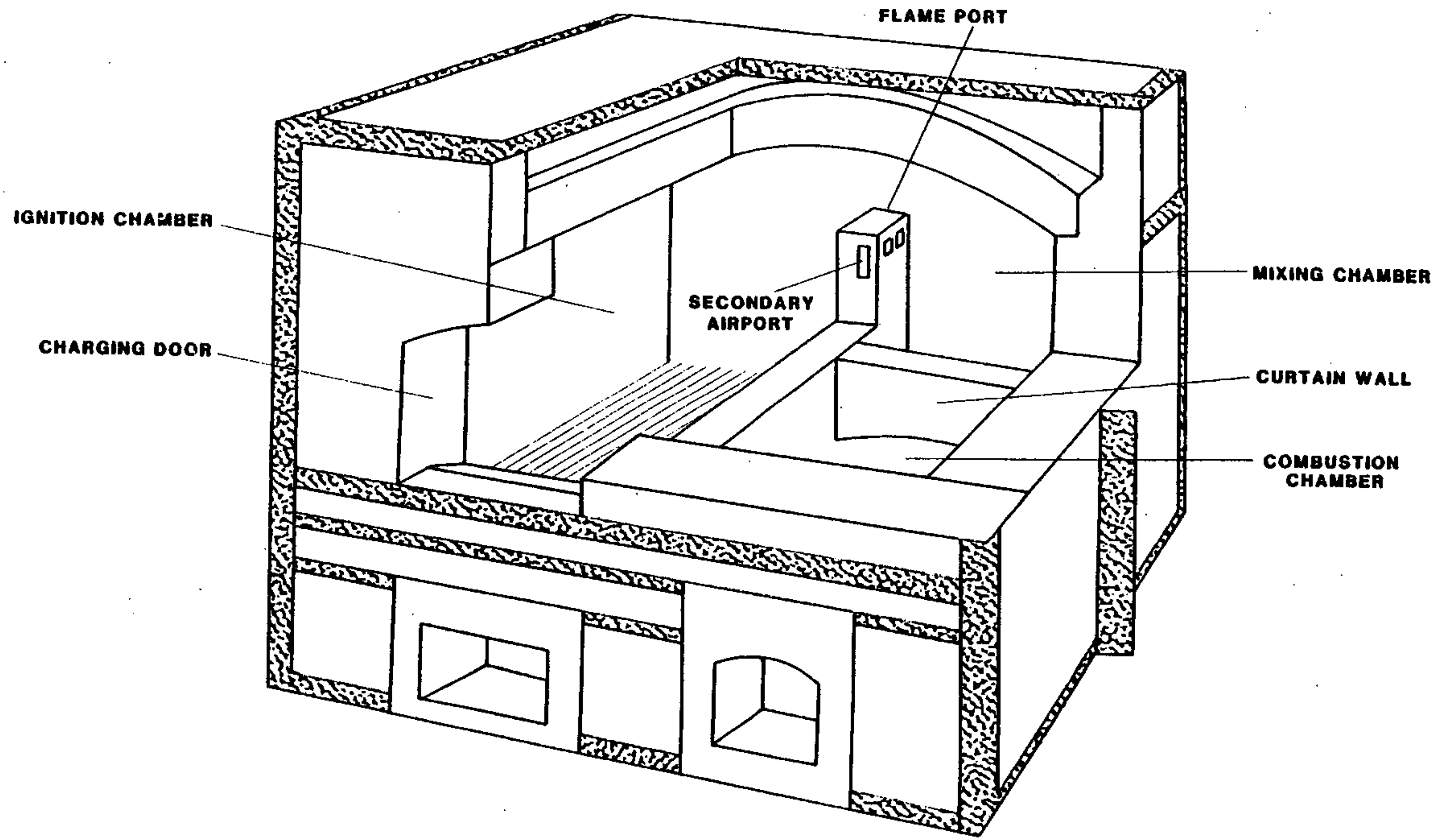


Figure D.6 Multiple Chamber Retort Incinerator

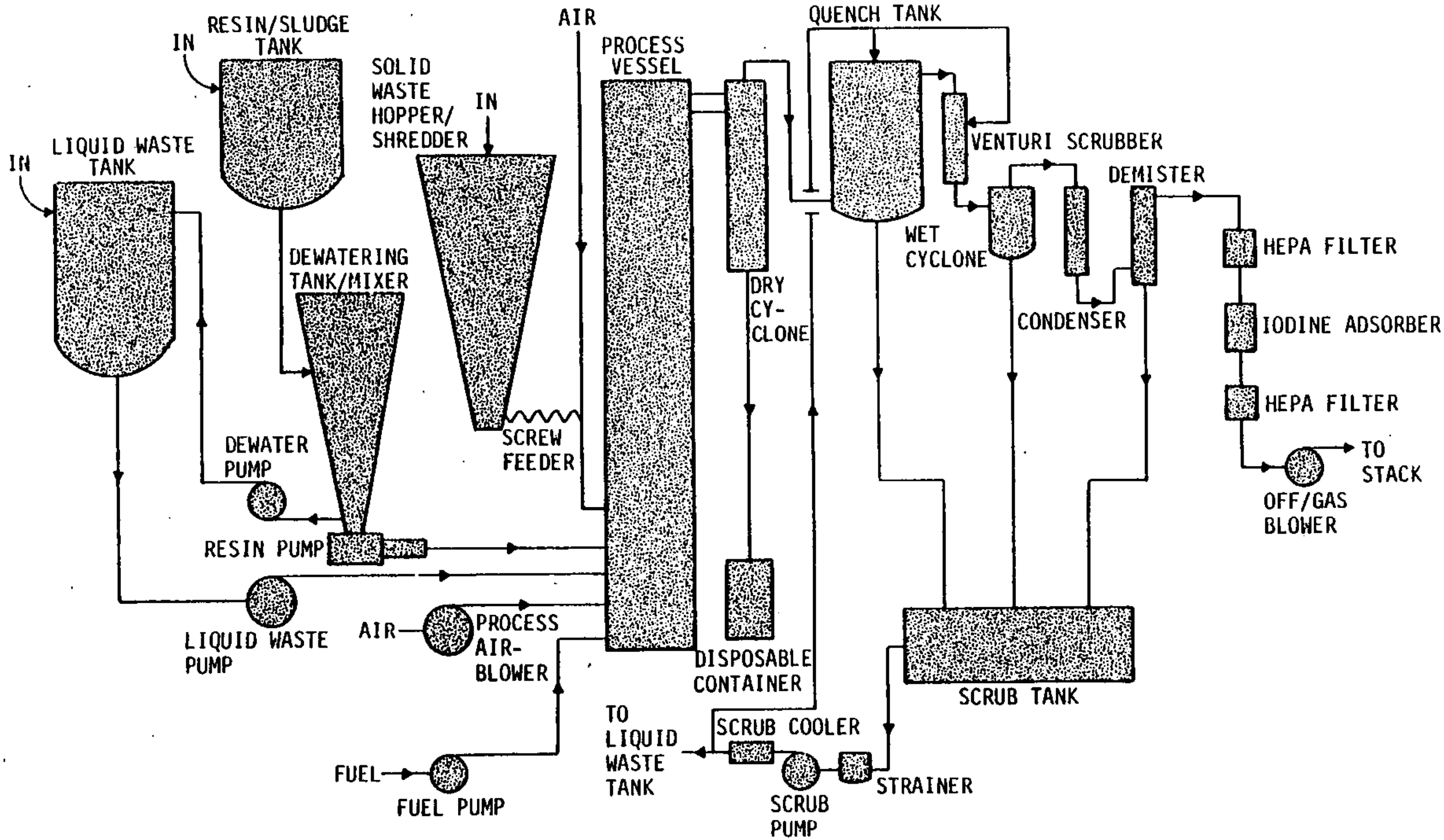


Figure D.7 Flow Diagram of Calciner/Incinerator for many years in nonnuclear industries to produce dry solids from liquid wastes by complete evaporation of the water. Typical fluidized bed incinerators can burn trash, organic solvents, and ion exchange resins. Wastes are normally screened to remove metal objects and shredded before entering the process vessel. The process vessel is maintained at 800 to 1000°C. Residual ash from the combustion process is collected for solidification. Ash carried out of the process vessel with the hot effluent gas stream is separated from the effluent gas by an off-gas treatment system, and also collected for subsequent solidification.

Recent investigations (Ref 38) indicate that thermal combustion is apparently the most effective way of removing chelating agents and organic chemicals from waste streams.

4.2 Volume Increase

There are three basic processes that can be applied to waste streams that result in an overall waste volume increase: solidification, addition of absorbent materials, and packaging. The activity per unit volume of the product stream is generally lower than that of the input waste.

The volume increase factor (VIF) is defined in this appendix as the ratio of the volume of the treated waste product to the volume of the input untreated waste.

4.2.1 Solidification

This section considers a number of solidification processes that can be applied to waste streams such as LWR process wastes (concentrated liquids, resins, filter sludges, and cartridge filters), or dry salts and ashes produced by calciners and incinerators. Cartridge filters are assumed to be solidified by pouring the solidification agent into the spaces between the currently utilized shipping containers and the cartridges. This results in no change to the currently shipped volume of the waste stream.

The solidification agents or techniques considered in this appendix are selected from those that are currently in use or are being actively marketed. These include cement, urea-formaldehyde and other synthetic polymer systems.

Absorbents such as vermiculite and diatomaceous earth are not considered to be solidification agents since they do not chemically or physically bind the wastes. Both cement and urea-formaldehyde solidification systems are currently used by LWRs. Bitumen (another agent) and vinyl ester-styrene (a synthetic polymer) are being actively marketed. Several bitumen solidification systems (which are widely used in Europe) have been sold but are not yet operational in this country. Synthetic polymer systems are being currently used in LWRs, including the Dresden-Unit 1 nuclear power plant, where decontamination solutions are to be solidified. Polyester (another synthetic polymer) has been evaluated in laboratory and pilot plant studies using simulated LWR liquid wastes and may be routinely used in the future.

In the analyses to determine the performance and technical requirements for disposal of LLW, three solidification scenarios are postulated:

- o Solidification Scenario A assumes continuation of existing practices resulting in waste performance characteristics that are comparatively less desirable than the following two solidification scenarios. This is simulated by assuming that 50 percent of the waste stream is solidified using urea-formaldehyde systems and the other 50 percent using cement systems.

- o Solidification Scenario B assumes improved waste performance characteristics over the previous case. This is simulated by assuming that 50 percent of the waste stream is solidified using cement systems and the other 50 percent using synthetic polymer systems.

- o Solidification Scenario C assumes further improved waste performance characteristics achievable with currently available technology. This is simulated by assuming that the waste stream is all solidified using synthetic polymer systems.

These solidification processes, volume increase factors, and the unit impact measures associated with the processes are summarized in Table D.19.

Table D.19 Solidification Techniques and Impacts

Solidification Technique	Cost* per m^3	Man-Hours* per m^3	Fuel Use* Gallons per m^3	Waste Streams	Volume Increase Factor
Scenario A	$1,282	24	40	P-CONCLIQ	1.4
				B-CONCLIQ	1.4
Scenario B	$1,873	24	40	P-IXRESIN	1.65
				P-CONCLIQ	1.82
				P-FSLUDGE	1.65
				B-IXRESIN	1.65
				B-CONCLIQ	1.56
				B-FSLUDGE	1.65
				I-ABSLIQD	1.65
Scenario C	$2,445	24	40	P-IXRESIN	2.00
				P-CONCLIQ	2.00
				P-FSLUDGE	2.00
				B-IXRESIN	2.00
				B-CONCLIQ	2.00
				B-FSLUDGE	2.00
				I-ABSLIQD	2.00
				All Ash	2.00

*Cost and man-hours are given per unit volume of treated waste. Impact measures are developed References 32 and 41-43.

4.2.2 Absorbent Materials

Absorbent materials such as diatomaceous earth or vermiculite are currently added to several institutional waste streams to minimize potential transportation impacts. These streams include liquid scintillation vial (LSV) waste, absorbed liquid waste, and biowaste. Existing commercial disposal facility operators require that these wastes be packaged with specified proportions of waste to absorbent material before they are accepted for disposal (Refs. 1, 40). For example, LSV waste is required to be packaged using sufficient absorbent material to absorb twice the total volume of the liquid in the package (Ref. 40). Lime is frequently added to the biowaste stream. Double packaging of these waste streams is also used for additional safety. For the liquid scintillation vial and the absorbed liquid waste streams, a volume increase factor of 3.0 is assumed. For the biowaste stream, a volume increase factor of 1.92 is assumed.

The practice of packaging wastes with absorbent material increases the difficulty of processing these wastes with currently available methods, if delivered to a centralized processing facility. This is because many of the common absorbent materials, an integral part of the waste stream when the package leaves the waste generator, are not incinerable; absorbents that are incinerable are either not cost-effective or not compatible with the waste streams. Other processing techniques are either not compatible with the waste streams (e.g., cement solidification of liquid scintillation vials) or would result in an increase of the volume of the waste, and as a consequence would not be cost-effective. Therefore, these wastes would have to be processed by the waste generator. While many waste generators are capable of implementing their own waste processing alternatives, such as solidification instead of use of absorbent material, there is no alternative cost-effective treatment method (other than the use of absorbents) for small waste generators such as individual physicians, small medical groups, and small colleges for several waste streams. Therefore, the option of processing at a regional center was not implemented for the I+LQSCNVL, I+ABSLIQD, and I+BIOWAS waste streams.

4.2.3 Packaging

Waste packaging also results in an overall increase in waste volume where the complete container volume is not utilized. Generally the waste generator attempts to minimize void volume within containers. For purposes of determining the performance objectives and technical requirements for disposal, the waste volume increase due to packaging (which results in decreased radionuclide concentrations) is conservatively neglected. Moreover, there is little applicable data available on the packaging efficiency of waste streams. The uncertainties in other estimates in this appendix partially compensate for exclusion of packaging efficiency from volume calculations.

Five generic types of waste containers were considered in this appendix: large wooden boxes (128 ft^3), small wooden boxes (16 ft^3), 55-gallon drums (7.5 ft^3), small liners (55 ft^3), and large liners (170 ft^3).

4.3 High Integrity Containers

It has been standard practice in the past to assume no confinement capability following disposal for the containers in which wastes are shipped to disposal facilities. There is little data available, but the data that does exist indicates that there is great variability in the length of time in which the containers retain their form and/or integrity after disposal.

There are many variables that may affect the integrity of currently used waste containers after disposal. These variables include the stability of the waste form (compactibility, resistance to biologic attack, etc.), the void volume of the container (packaging efficiency), the characteristics of the disposal facility site (natural elements such as precipitation and humidity), the depth of disposal (static soil pressures), and the chemical characteristics of the surrounding soils and wastes (corrosiveness). Because of the many unquantifiable and site specific variables, no attempt has been made in this appendix to estimate and incorporate a confinement capability for typical containers.

However, the concept of a high-integrity container (HIC) may be considered as an alternative to waste processing as a means of improving the waste form. In this case, the container would be constructed in a much more robust manner than the containers generally used to transport wastes to disposal facilities. The HIC would be designed to resist crushing from static loads and corrosion from the contained wastes as well as the surrounding soils. The HIC would therefore provide the needed support to disposal cell covers to minimize subsidence and to reduce infiltration. In addition, since the wastes would be contained inside the HIC, leaching of radionuclides from the HIC would be negligible as long as the HIC retained its integrity. (Note that corrosion of a portion of an HIC, which could compromise its ability to withstand leaching, would not be expected to generally reduce its ability to provide structural support for the disposal cell covers.)

Since HICs have not been extensively used for packaging wastes for disposal, there is less data with which to compare other impact measures such as costs or occupational exposures. These, however, may be discussed in a qualitative manner using solidification of LWR ion-exchange resins and filter media as an example. Use of an HIC would be expected to be more expensive than merely dewatering the resins and filter media but less expensive than solidification. This is because no new equipment would need to be installed at the waste generator's facility. Additional expenses would involve construction and certification of HICs. Since unlike solidification, there would be no increase in waste volume using HICs, transportation costs and disposal costs would probably be lower than the solidified case. Occupational exposures from waste processing operations at the waste generator would not be expected to vary significantly from those received during management of LWR process wastes under existing practices. The same types of waste handling, processing, transport and disposal operations would be carried out; one is merely substituting one container design for another. Finally, unlike solidification, there would be no decrease in land use efficiency at a disposal facility compared with the dewatered case. The energy use would also probably be lower than for the solidified case.

Use of HICs as an alternative to solidification of ion-exchange resins and filter media is allowed by the South Carolina Department of Health and Environmental Control, the state agency regulating disposal of waste at the Barnwell, S.C. disposal facility. Performance criteria for HICs for the Barnwell facility have been drafted by South Carolina and these are listed in Table D.20.

Table D.20 State of South Carolina Criteria for High Integrity Containers

The general criteria for high integrity containers to be used for high concentration waste forms is as follows:

1. The container must be capable of maintaining its contents until the radionuclides have decayed approximately 300 years, since two of the major isotopes of concern in this respect are strontium-90 and cesium 137 with half-lives of 28 and 30 years, respectively.
2. The structural characteristics of the container with its contents must be adequate to withstand all the pressure and stresses it will encounter during all handling, lifting, loading, offloading, backfilling, and burial.
3. The container must not be susceptible to chemical, galvanic or other reactions from its contents or from the burial environment.
4. The container must not deteriorate when subjected to the elevated temperatures of the waste streams themselves, from processing materials inside the container, or during storage, transportation and burial.
5. The container must not be degraded or its characteristics diminished by radiation emitted from its contents, the burial trench or the sun during storage.
6. All lids, caps, fittings and closures must be of equivalent materials and construction to meet all of the above requirements and must be completely sealed to prevent any loss of the container contents.

Source: Reference 45.

One HIC design which has been recently approved by the South Carolina Department of Health and Environmental Control is currently being marketed. The HIC is constructed principally of polyethylene and is currently available in designs ranging from 2.4 m^3 (84 ft^3) to 9 m^3 (316 ft^3). Given adequate lead time for fabricating, special designs are advertised as being available upon request. Costs for a HIC are estimated to run approximately 75% to 85% higher than an equivalently sized carbon steel liner (Ref. 44).

5. ALTERNATIVE WASTE SPECTRA

This section describes the four waste spectra that are utilized in the EIS to help determine the performance objectives and technical requirements for acceptable disposal of LLW. The concept "spectrum" as used here denotes the total volume and properties of the waste streams (the 36 streams given in Table D.5) generated between the years 1980 and 2000 after they have been processed by a set of selected waste treatment options. Each spectrum corresponds to a general level of waste performance in terms of waste stability, resistance to wind mobilization, resistance to leaching, and physical, chemical, and radiological properties that can be achieved by establishing operational and/or administrative requirements. The spectra differ significantly in waste volumes, radioactive concentrations, and performance.

5.1 Waste Spectra Descriptions

The radioactive concentrations of each waste stream for each spectrum depends on the change in the volume of the stream during processing. Whenever a process is applied to a waste stream that results in volume reduction of the stream, its concentrations are increased accordingly. Similarly, whenever a process is applied that results in a volume increase, the concentrations are decreased accordingly. The minute quantities of radionuclides that are lost during these processes (e.g., the radionuclides may become attached to the process vessel walls) have been conservatively neglected.

The four waste spectra are used to consider the range in waste performance that can be achieved through alternative operational and/or administrative requirements. With each respective spectra, increased waste processing is assumed. This results in waste forms having greater stability, better leaching characteristics, lessened dispersibility, lower volumes, and higher concentrations. The effect of these alterations in waste form and radionuclide concentrations on radiological impact measures such as groundwater migration and to exposures to potential inadvertent intruders may be compared against costs and other nonradiological impact measures.

In developing the spectra, it was recognized that a considerable amount of change is currently taking place in existing waste processing and packaging techniques. This relatively rapid change makes it difficult to characterize current waste processing and packaging practices. For example, due to the current limitation in disposal capacity, there is increased use of volume reduction procedures (such as use of compactors) by waste generators. In addition, license conditions at two disposal facilities are requiring that resins and filter media be either solidified or placed into high integrity containers prior to disposal.

Therefore, the first two spectra were estabished to more or less straddle existing practice. Spectrum 1 represents existing or past practices while Spectrum 2 represents in many respects the direction that waste processing and packaging practices seem to be headed. Waste Spectra 3 & 4 represent more extreme waste processing and packaging practices.

The general assumptions made in these spectra are presented below.

Waste Spectrum 1

This spectrum assumes a continuation of past or existing waste management practices. Some of the LWR waste streams are solidified (P-CONCLIQ, B-CONCLIQ, L-DECONRS). However, no processing is performed on combustible wastes or streams containing chelating agents or organic chemicals. The following general assumptions are made:

- LWR resins and filter sludges are assumed to be shipped to disposal facilities in a dewatered form.
- PWR cartridge filters are packaged for shipment by placing the filters within in a 55-gallon drum. The resulting void spaces within the waste container results in a structually unstable waste form.
- LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified. The solidification binders used are assumed to be half cement and half urea-formaldehyde (solidification Scenario A).
- No special effort is made to compact trash.
- Institutional waste streams are shipped to disposal facilities after they are packaged with currently utilized absorbent materials.
- Resins from LWR decontamination operations (L-DECONRS stream) are solidified in a synthetic polymer (solidification Scenario C).
- Four relatively high activity waste streams principally containing activated metal (P-NCTRASH, B-NCTRASH, L-NFRCOMP, and N-HIGHACT) are assumed to be packaged according to existing practice--i.e., waste streams are placed into containers and the interstitial spaces filled with material such as compressible waste forms. Although the waste itself is stable, the packaging practice results in an unstable waste form.

Waste Spectrum 2

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification Scenario B). LWR concentrated liquids are additionally reduced in volume through an evaporator/crystallizer. Routine compaction is performed on all compactible trash. For certain streams (see below), half of the trash volume is compacted at the facility generating the waste and the other half at a centralized processing facility. The following general assumptions are made:

- All LWR concentrated liquids are evaporated to 50 weight percent solids, and all LWR process wastes are solidified using solidification Scenario B. In the case of cartridge filters, the solidification agent fills voids in the packaged waste but is assumed to not increase the volume of the waste stream.
- At large facilities, liquid scintillation vials are crushed and packaged in absorbent material (the I-LIQSCVL stream).

- o All compactible trash streams are compacted; the P-COTRASH, B-COTRASH, F-COTRASH, I-COTRASH, N-SSTRASH, and N-LOTRASH streams are compacted at the source of generation; the I+COTRASH, N+SSTRASH, and N+LOTRASH streams are compacted at a centralized regional processing facility.

- o Liquids from medical isotope production (N-ISOPROD) are solidified using solidification Scenario C.

- o The P-NCTRASH, B-NCTRASH, L-NFRCOMP, and N-HIGHACT streams are assumed to be stabilized. Instead of packaging these waste streams in easily degradable trash, void spaces between the waste and the container are filled with a nondegradable material such as sand.

Waste Spectrum 3

In this spectrum, LWR process wastes, including filter cartridges, are solidified assuming that further improved waste solidification agents are used (solidification Scenario C). LWR concentrated liquids are first evaporated to 50 weight percent solids. All possible incineration of combustible material (except LWR process wastes) is performed. Some incineration is done at the source of generation (fuel cycle trash, LWR decontamination resins, institutional wastes from large facilities and industrial trash from large facilities), and some at a centralized regional processing facility (institutional and industrial trash from small facilities). All incineration ash is solidified using solidification Scenario C. The B-NCTRASH, P-NCTRASH, L-NFRCOMP, and N-HIGHACT streams are again assumed to be stabilized through improved packaging.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All wastes amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification Scenario C. LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All noncompactible wastes are reduced in volume at a centralized processing facility using a large hydraulic press. The L-NFRCOMP and N-HIGHACT streams are stabilized. This spectrum represents about the maximum volume reduction that can currently be practically achieved.

5.2 Spectrum Data File Components

For each of the four waste spectra, a data file was constructed consisting of three major groups of waste form and packaging parameters:

- o Volume reduction and volume increase factors;

- o Waste form behavior indices (six indices total); and

- o Waste processing procedures;

The first three groups of parameters are discussed in this section. Another group of parameters which are used to estimate population exposure, occupational exposures, and costs of waste transportation to a disposal facility are described in Appendix G.

Volume Reduction and Volume Increase Factors

These factors were previously introduced in Section 4. The volume reduction factor (VRF) is the ratio of the volume of the untreated input waste to the volume of the treated waste product. It is used in quantifying the effects of the volume reduction processes discussed in Section 4.1. The volume increase factor (VIF) is defined as the ratio of the volume of the product waste stream to the volume of the input waste stream. It is used in quantifying the effects of the volume increase processes discussed in Section 4.2.

The volume reduction and volume increase factors associated with each of the 36 waste streams for each of the 4 waste spectra considered in this appendix are presented in Table D.21.

Waste Form Behavior Indices

The effects of different waste performances discussed above must be included in the impact analyses. One such tool is quantifying these properties through discrete indices that trigger specific computational procedures in the impacts analyses. This is the approach adopted in this appendix. Additional information regarding this approach may be found in Section 3 of Appendix G.

The characteristics important in determining the effects of different waste behavior include the flammability of the waste form at the time of disposal, the dispersibility of the waste form several decades after disposal, the structural stability of the waste, the resistance of the waste form to leaching, the accessibility of the radionuclides to transfer agents such as wind or water, and the relative mobility of the radionuclides (the presense or absence of chelating agents or organic chemicals). These six properties were quantified through six waste form behavior indices defined in Table D.22 and discussed below.

The flammability index ranks waste forms according to their flammability prior to disposal. Waste forms that will not burn even on prolonged exposure to open flame and moderately intense heat (Refs. 45, 46) are assigned an index of (0). Those waste forms that will sustain combustion are assigned an index of (3). Between these extremes are two additional flammability categories. Waste forms that will ignite but will not sustain burning under these conditions are assigned an index of (2). Waste forms consisting of a mixture of materials with flammability indices (0) and (2) (e.g., solidification Scenarios A and B) are assigned an index of (1).

The dispersibility index is a qualitative measure of the potential for suspension of radioactivity, should the waste form be exposed to wind after a significant period (on the order of 100 years). Waste forms which are judged to have a

Table D.21 Volume Reduction and Increase Factors

	SPECTRUM 1		SPECTRUM 2		SPECTRUM 3		SPECTRUM 4	
STREAM	VRF	VIF	VRF	VIF	VRF	VIF	VRF	VIF
P-IXRESIN	1.00	1.00	1.00	1.65	1.00	2.00	18.00	2.00
P-CONCLIQ	1.00	1.40	6.00	1.82	6.00	2.00	8.00	2.00
P-FSLUDGE	1.00	1.00	1.00	1.65	1.00	2.00	5.00	2.00
P-FCARTRG	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B-IXRESIN	1.00	1.00	1.00	1.65	1.00	2.00	18.00	2.00
B-CONCLIQ	1.00	1.40	2.40	1.56	2.40	2.00	6.40	2.00
B-FSLUDGE	1.00	1.00	1.00	1.65	1.00	2.00	5.00	2.00
P-COTRASH	1.00	1.00	2.00	1.00	80.00	2.00	80.00	2.00
P-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
B-COTRASH	1.00	1.00	2.00	1.00	80.00	2.00	80.00	2.00
B-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
F-COTRASH	1.00	1.00	1.50	1.00	40.00	2.00	40.00	2.00
F-NCTRASH	1.00	1.00	1.00	1.00	1.00	1.00	6.00	1.00
I-COTRASH	1.00	1.00	2.00	1.00	20.00	2.00	20.00	2.00
I+COTRASH	1.00	1.00	4.00	1.00	80.00	2.00	80.00	2.00
N-SSTRASH	1.00	1.00	1.50	1.00	10.00	2.00	10.00	2.00
N+SSTRASH	1.00	1.00	3.00	1.00	40.00	2.00	40.00	2.00
N-LOTRASH	1.00	1.00	2.00	1.00	20.00	2.00	20.00	2.00
N+LOTRASH	1.00	1.00	4.00	1.00	80.00	2.00	80.00	2.00
F-PROCESS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
U-PROCESS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I-LQSCNVL	1.00	3.00	1.28	3.00	4.52	2.00	4.52	2.00
I+LQSCNVL	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00
I-ABSLIQD	1.00	3.00	1.00	1.65	1.00	2.00	100.00	2.00
I+ABSLIQD	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00
I-BIOWAST	1.00	1.92	1.00	1.92	15.00	2.00	15.00	2.00
I+BIOWAST	1.00	1.92	1.00	1.92	1.00	1.92	1.00	1.92
N-SSWASTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-LOWASTE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-NFRCOMP	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-DECONRS	1.00	2.00	1.00	2.00	18.00	2.00	18.00	2.00
N-ISOPROD	1.00	1.30	1.00	2.00	1.00	2.00	1.00	2.00
N-HIGHACT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-TRITIUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-SOURCES	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N-TARGETS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table D.22 Waste Form Behavior Indices

Parameter	Symbol	Indices
Flammability	(I4)	0 = nonflammable
		1 = low flammability (mixture of material with indices of 0 and 2)
		2 = burns if heat supplied (does not support burning)
		3 = flammable (supports burning)
Dispersibility	(I5)	0 = low
		1 = slight to moderate
		2 = moderate
		3 = severe
Leachability	(I6)	1 = unsolidified waste form
		2 = solidification scenario A
		3 = solidification scenario B
		4 = solidification scenario C
Chemical Content	(I7)	0 = no chelating agents or organic chemicals
		1 = chelating agents or organic chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form
		1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible
		2 = moderately accessible
		3 = accessible with difficulty

low probability of becoming suspended into respirable particles are assigned an index of (0). Those waste forms that have a high potential of becoming suspended into respirable particles are assigned an index of (3). Waste forms that tend to crumble or fracture extensively and those subject to relatively rapid (within about 100 years) decomposition are assigned an index of (2). Waste forms consisting of a mixture of materials with dispersibility indices of (0) and (2) are assigned an index of (1).

The leachability index is a qualitative measure of the waste form's resistance to leaching and is determined by the solidification procedures used. Unsolidified waste forms, which are assumed to be readily leached, are assigned an index of (1). Solidification scenarios A, B, and C (discussed in the previous section) are assigned an index of 2, 3, and 4, respectively.

The chemical content index denotes whether the waste form may contain chelating agents or organic chemicals that may increase the mobility during leaching and subsequent migration from the disposal cell. An index value of (0) indicates a likelihood that these chemicals or agents are absent, whereas an index value of (1) indicates a likelihood of their presence.

The stability index denotes whether the waste form is likely to reduce in volume after disposal due to compressibility, large internal void volumes, and/or chemical and biological attack. With the exception of waste streams packaged in high integrity containers (assigned an index of 1), no credit is taken for the waste containers. An index value of (0) indicates the likelihood of structural instability, whereas a value of (1) indicates a structurally stable waste form.

The last index, the accessibility index, ranks the waste forms according to the accessibility of the radionuclides to transfer agents such as wind or water. It essentially denotes a correction factor in the analyses for activated metals or metals having fixed surface contamination. Surface contaminated wastes and waste containing radioactivity in readily soluble forms are assigned an index of (1). The waste forms that are almost exclusively activated metals with imbedded radioactivity not readily accessible to the elements are assigned an index of (3). Other waste forms (e.g., noncompactible trash that contains a lot of equipment) are assigned an index of (2).

A single waste property may determine the value of more than one index and a single performance characteristic may be described by more than one index. For example, in Spectra 1 and 2, the tendency of combustible materials in the trash waste streams to decompose contributes to both the dispersibility and the instability of these streams. On the other hand, the ability of a waste form to retain the radioactivity it contains is described by both its leachability and its accessibility. In this case, leachability is based on the properties of the waste binder (solidification agent) while accessibility is based on the properties of the waste itself.

Waste behavior indices that have been assumed for each of the 36 waste streams for each of the four spectra are presented in Table D.23.

Processing Impacts

Processing impacts in addition to those associated with treatment operations performed in Spectrum 1 include population exposures, occupational exposures, costs, and energy use.

Population impacts from processing depend primarily on the radioactive contents of the waste streams and secondarily on the location at which the processing

Table D.23 Waste Form Behavior Indices for Waste Spectra 1-4

INDEX I	SPECTRUM 1 4 5 6 7 8 9*	SPECTRUM 2 4 5 6 7 8 9*	SPECTRUM 3 4 5 6 7 8 9*	SPECTRUM 4 4 5 6 7 8 9*
P-IXRESIN	2 1 1 0 0 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
P-CONCLIQ	1 1 2 0 1 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
P-FSLUDGE	1 3 1 0 0 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
P-FCARTRG	2 2 1 0 0 1	1 1 3 0 1 1	2 0 4 0 1 1	2 0 4 0 1 1
B-IXRESIN	2 1 1 0 0 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
B-CONCLIQ	1 1 2 0 1 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
B-FSLUDGE	1 3 1 0 0 1	1 1 3 0 1 1	2 0 4 0 1 1	1 0 4 0 1 1
P-COTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
P-NCTRASH	0 0 1 0 0 2	0 0 1 0 1 2	0 0 1 0 1 2	0 0 1 0 1 2
B-COTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
B-NCTRASH	0 0 1 0 0 2	0 0 1 0 1 2	0 0 1 0 1 2	0 0 1 0 1 2
F-COTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
F-NCTRASH	0 0 1 0 0 2	0 0 1 0 0 2	0 0 1 0 0 2	0 0 1 0 1 2
I-COTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
I+COTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
N-SSTRASH	2 2 1 0 0 1	2 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
N+SSTRASH	2 2 1 0 0 1	2 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
N-LOTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
N+LOTRASH	3 2 1 0 0 1	3 2 1 0 0 1	1 0 4 0 1 1	1 0 4 0 1 1
F-PROCESS	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1
U-PROCESS	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1
I-LQSCNVL	3 3 1 1 0 1	3 3 1 1 1 1	0 0 4 0 1 1	0 0 4 0 1 1
I+LQSCNVL	3 3 1 1 0 1	3 3 1 1 0 1	3 3 1 1 0 1	3 3 1 1 0 1
I-ABSLIQD	3 3 1 1 1 1	3 1 3 1 1 1	1 0 4 0 1 1	1 0 4 0 1 1
I+ABSLIQD	3 3 1 1 1 1	3 3 1 1 1 1	3 3 1 1 1 1	3 3 1 1 1 1
I-BIOWAST	2 3 1 1 0 1	2 3 1 1 0 1	0 0 4 0 1 1	0 0 4 0 1 1
I+BIOWAST	2 3 1 1 0 1	2 3 1 1 0 1	2 3 1 1 0 1	2 3 1 1 0 1
N-SSWASTE	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1	0 3 1 0 1 1
N-LOWASTE	3 3 1 1 0 1	3 3 1 1 0 1	3 3 1 1 0 1	3 3 1 1 1 1
L-NFRCOMP	0 0 1 0 0 2	0 0 1 0 1 2	0 0 1 0 1 2	0 0 1 0 1 2
L-DECONRS	2 0 4 1 1 1	2 0 4 1 1 1	1 0 4 0 1 1	1 0 4 0 1 1
N-ISOPROD	1 1 3 1 0 1	1 0 4 1 1 1	1 0 4 1 1 1	1 0 4 1 1 1
N-HIGHACT	0 0 1 0 0 3	0 0 1 0 1 3	0 0 1 0 1 3	0 0 1 0 1 3
N-TRITIUM	3 3 1 1 1 1	3 3 1 1 1 1	3 3 1 1 1 1	3 3 1 1 1 1
N-SOURCES	0 0 1 0 1 2	0 0 1 0 1 2	0 0 1 0 1 2	0 0 1 0 1 2
N-TARGETS	0 0 1 0 1 1	0 0 1 0 1 1	0 0 1 0 1 1	0 0 1 0 1 1

*I4=Flammability index, I5=dispersability index, I6=leachability index, I7=Chemical content index, I8=stability index, and I9=accessability index.

takes place. Only incineration (pathological incinerators and incinerator/calciners) were assumed to result in a release of radioactivity which could result in potentially significant additional population exposures. Occupational exposures depend on the environment in which the waste processing is being performed in addition to the waste activity. The cost of waste processing also depend on the size of the facility as well as the specific process being utilized.

In order to account for these variations, four indices have been assigned to each waste stream in each spectrum and are utilized in the calculation of waste processing impacts. The values of these indices trigger specific calculational procedures in the calculation of the impact measures.

The first index denotes the volume reduction process (if any) utilized for the waste stream. An index value of (0) implies no volume reduction. Index values of (1), (2), and (3) indicate routine compaction, improved compaction, and hydraulic press compaction, respectively. An index value of (4) indicates evaporation, and index values of (5), (6), and (7) indicate incineration using a pathological incinerator, fluidized-bed calcination at a small facility, and fluidized-bed calcination at a large facility, respectively.

The second index denotes the solidification processes (if any) applied to the waste stream. An index value of (0) indicates an unsolidified waste form. Index values of (1), (2), and (3) indicate use of solidification Scenarios A, B, and C, respectively.

The third index denotes whether the processing (if any) takes place at the waste generator or at a centralized processing facility. An index value of (0) indicates no processing; an index value of (1) indicates processing by the waste generator; and an index value of (2) indicates processing at the centralized processing facility.

The last index indicates the environment of the location at which the processing is assumed to occur. An index value of (0) indicates no processing; an index value of (1) indicates an urban environment; and an index value of (2) indicates a rural environment.

The values assigned for these indices for all the waste streams and the waste spectra considered in this report are presented in Table D.24. More information on the calculation of the waste processing impacts can be found in References 5 and 46, as well as Appendix G.

5.3 Waste Volumes and Radionuclide Concentrations

The "untreated" waste volumes projected to be generated to the year 2000 for each of the 4 regions considered in this appendix (USNRC Regions 4 and 5 were combined into one region for purposes of this appendix) were presented in Table D.9. The waste stream volumes after processing for each of the 4 spectra for each region may then be determined by multiplying the volume of each stream in Table D.9 by the appropriate volume increase factor and dividing by the volume reduction factor given in Table D.21.

Table D-24 Processing Indices

INDEX	SPECTRUM 1 P	S	L	E*	SPECTRUM 2 P	S	L	E*	SPECTRUM 3 P	S	L	E*	SPECTRUM 4 P	S	L	E*
P-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
P-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-FCARTRG	0	1	1	0	0	2	1	0	0	3	1	0	0	3	1	0
B-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
B-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
B-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
P-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
B-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
B-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
F-COTRASH	0	0	0	0	1	0	1	0	6	3	1	1	6	3	1	1
F-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0
I-COTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
I+COTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-SSTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+SSTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-LOTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+LOTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
F-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I-LQSCNVL	0	0	1	0	1	0	1	0	5	3	1	1	5	3	1	1
I+LQSCNVL	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-ABSLIQD	0	0	1	0	0	2	1	0	0	3	1	0	5	3	1	1
I+ABSLIQD	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-BIOWAST	0	0	1	0	0	0	1	0	5	3	1	1	5	3	1	1
I+BIOWAST	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
N-SSWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-LOWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-NFRCOMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-DECONRS	0	3	1	0	0	3	1	0	6	3	1	2	6	3	1	2
N-ISOPROD	0	2	1	0	0	3	1	0	0	3	1	0	0	3	1	0
N-HIGHACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TRITIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-SOURCES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TARGETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*P = Volume reduction process index, S = solidification process index, L = waste processing location index, E = processing environment index

The regional volumes are useful but it is difficult to directly use the regional volumes in the analysis to determine acceptable performance objectives and technical criteria for LLW disposal. What is needed is a normalized set of volumes which represents the waste contributed by all the regions and which can be used to compare the costs and impacts of one alternative against another. To do this, the volumes for each of the 4 regions are summed for each waste stream and each waste spectra as shown in Table D.25. (As shown, about 3.62 million m^3 (127.8 million ft^3) of waste is projected to be generated in the United States to the year 2000.) These waste volumes are then normalized to one million m^3 for waste spectrum one as shown in Table D.26. One million m^3 bounds the projected waste volumes projected to be generated by a single region. As shown, the range in waste processing options considered results in a total volume reduction from Spectrum 1 to Spectrum 4 by about a factor of 4.

Radionuclide concentrations for any waste stream may then be obtained by multiplying the untreated waste concentrations (e.g., Tables D.11 through D.14) by the volume increase and dividing by the volume reduction factors for the processed volume of interest. This may be performed for the regional volumes, the normalized volumes, and for any of the four spectra. In general, radionuclides potentially lost from the waste forms during processing operations are conservatively not considered when determining processed waste concentrations. An exception is loss of tritium and carbon-14 from the processed waste form due to airborne releases of these two radionuclide from processing options involving incineration and calcination. As discussed in Appendix G and in Reference 46, the assumed release fractions for tritium and carbon-14 from waste forms processed by incineration or calcination are as follows:

	Release Fraction	
Nuclide	Pathological Incinerator	Calciner
H-3	0.90	0.90
C-14	0.75	0.25

The amounts of these two radionuclides contained in the final processed form are reduced appropriately.

Finally, two sets of concentrations are used in this environmental impact statement, depending upon the radioactivity exposure pathways considered. To evaluate impacts due to potential operational accidents or to a potential inadvertent intruder following the end of active institutional controls, spectral concentrations are used which are calculated using the untreated concentrations in Tables D.11 through D.14 as modified by the appropriate volume increase and reduction factors for the waste spectrum considered. This corresponds to the concentrations of the waste delivered to the disposal facility each year during its 20 year operating life, and neglects the radioactive decay that takes place after generation and prior to disposal.

Table D.25 Cumulative Waste Volumes (m^3)

STREAM	SPECTRUM 1 VOLUME	SPECTRUM 1 % VOL	SPECTRUM 2 VOLUME	SPECTRUM 2 % VOL	SPECTRUM 3 VOLUME	SPECTRUM 3 % VOL	SPECTRUM 4 VOLUME	SPECTRUM 4 % V
P-IXRESIN	3.46E+04	.96	5.71E+04	2.26	6.93E+04	3.88	3.85E+03	.4
P-CONCLIQ	3.41E+05	9.43	7.38E+04	2.92	8.12E+04	4.55	6.09E+04	7.0
P-FSLUDGE	4.28E+03	.12	7.06E+03	.28	8.56E+03	.48	1.71E+03	.2
P-FCARTRG	2.18E+04	.60	2.18E+04	.86	2.18E+04	1.22	2.18E+04	2.5
B-IXRESIN	7.62E+04	2.11	1.26E+05	4.98	1.52E+05	8.54	8.47E+03	.9
B-CONCLIQ	2.94E+05	8.14	1.37E+05	5.41	1.75E+05	9.81	6.57E+04	7.6
B-FSLUDGE	1.69E+05	4.67	2.79E+05	11.04	3.38E+05	18.94	6.76E+04	7.8
P-COTRASH	4.24E+05	11.74	2.12E+05	8.40	1.06E+04	.59	1.06E+04	1.2
P-NCTRASH	2.18E+05	6.02	2.18E+05	8.62	2.18E+05	12.20	3.63E+04	4.2
B-COTRASH	2.09E+05	5.77	1.04E+05	4.13	5.22E+03	.29	5.22E+03	.6
B-NCTRASH	9.90E+04	2.74	9.90E+04	3.92	9.90E+04	5.54	1.65E+04	1.9
F-COTRASH	2.36E+05	6.52	1.57E+05	6.23	1.18E+04	.66	1.18E+04	1.3
F-NCTRASH	4.17E+04	1.15	4.17E+04	1.65	4.17E+04	2.34	6.95E+03	.8
I-COTRASH	1.41E+05	3.89	7.04E+04	2.79	1.41E+04	.79	1.41E+04	1.6
I+COTRASH	1.41E+05	3.89	3.52E+04	1.39	3.52E+03	.20	3.52E+03	.4
N-SSTRASH	1.80E+05	4.97	1.20E+05	4.74	3.59E+04	2.01	3.59E+04	4.1
N+SSTRASH	1.80E+05	4.97	5.99E+04	2.37	8.98E+03	.50	8.98E+03	1.0
N-LOTRASH	5.06E+04	1.40	2.53E+04	1.00	5.06E+03	.28	5.06E+03	.5
N+LOTRASH	5.06E+04	1.40	1.27E+04	.50	1.27E+03	.07	1.27E+03	.1
F-PROCESS	7.82E+04	2.16	7.82E+04	3.09	7.82E+04	4.38	7.82E+04	9.1
U-PROCESS	2.81E+04	.78	2.81E+04	1.11	2.81E+04	1.57	2.81E+04	3.2
I-LOSCNVL	1.47E+05	4.08	1.15E+05	4.56	2.17E+04	1.22	2.17E+04	2.5
I+LQSCNVL	1.47E+05	4.08	1.47E+05	5.84	1.47E+05	8.26	1.47E+05	17.1
I-ABSLIQD	1.68E+04	.46	9.22E+03	.36	1.12E+04	.63	1.12E+02	.0
I+ABSLIQD	1.68E+04	.46	1.68E+04	.66	1.68E+04	.94	1.68E+04	1.9
I-BIOWAST	3.02E+04	.83	3.02E+04	1.19	2.09E+03	.12	2.09E+03	.2
I+BIOWASR	3.02E+04	.83	3.02E+04	1.19	3.02E+04	1.69	3.02E+04	3.5
N-SSWASTE	6.34E+04	1.75	6.34E+04	2.51	6.34E+04	3.55	6.34E+04	7.3
N-LOWASTE	6.03E+04	1.67	6.03E+04	2.39	6.03E+04	3.38	6.03E+04	7.0
L-NFRCOMP	2.89E+03	.08	2.89E+03	.11	2.89E+03	.16	2.89E+03	.3
L-DECONRS	7.00E+04	1.93	7.00E+04	2.77	3.89E+03	.22	3.89E+03	.4
N-ISOPROD	6.75E+03	.19	1.04E+04	.41	1.04E+04	.58	1.04E+04	1.2
N-HIGHACT	2.61E+03	.07	2.61E+03	.10	2.61E+03	.15	2.61E+03	.3
N-TRITIUM	3.48E+03	.10	3.48E+03	.14	3.48E+03	.19	3.48E+03	.4
N-SOURCES	1.87E+02	.01	1.87E+02	.01	1.87E+02	.01	1.87E+02	.0
N-TARGETS	1.34E+03	.04	1.34E+03	.05	1.34E+03	.08	1.34E+03	.1
TOTALS	3.62E+06		2.53E+06		1.79E+06		8.59E+05	

Table D.26 Normalized Waste Volumes (m^3)

	SPECTRUM 1		SPECTRUM 2		SPECTRUM 3		SPECTRUM 4	
TREAM	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% VOL	VOLUME	% VOL
-IXRESIN	9.58E+03	.96	1.58E+04	2.26	1.92E+04	3.88	1.06E+03	.45
-CONCLIQ	9.43E+04	9.43	2.04E+04	2.92	2.24E+04	4.55	1.68E+04	7.08
-FSLUDGE	1.18E+03	.12	1.95E+03	.28	2.37E+03	.48	4.73E+02	.20
-FCARTRG	6.02E+03	.60	6.02E+03	.86	6.02E+03	1.22	6.02E+03	2.53
-IXRESIN	2.11E+04	2.11	3.48E+04	4.98	4.22E+04	8.54	2.34E+03	.99
-CONCLIQ	8.14E+04	8.14	3.78E+04	5.41	4.84E+04	9.81	1.82E+04	7.65
-FSLUDGE	4.67E+04	4.67	7.71E+04	11.04	9.35E+04	18.94	1.87E+04	7.87
-COTRASH	1.17E+05	11.74	5.87E-04	8.40	2.93E+03	.59	2.93E+03	1.23
-NCTRASH	6.02E+04	6.02	6.02E+04	8.62	6.02E+04	12.20	1.00E+04	4.22
-COTRASH	5.77E+04	5.77	2.88E+04	4.13	1.44E+03	.29	1.44E+03	.61
-NCTRASH	2.74E+04	2.74	2.74E+04	3.92	2.74E+04	5.54	4.56E+03	1.92
-COTRASH	6.52E+04	6.52	4.35E+04	6.23	3.26E+03	.66	3.26E+03	1.37
-NCTRASH	1.15E+04	1.15	1.15E+04	1.65	1.15E+04	2.34	1.92E+03	.81
-COTRASH	3.89E+04	3.89	1.95E+04	2.79	3.89E+03	.79	3.89E+03	1.64
+COTRASH	3.89E+04	3.89	9.73E+03	1.39	9.73E+02	.20	9.73E+02	.41
-SSTRASH	4.97E+04	4.97	3.31E+04	4.74	9.93E+03	2.01	9.93E+03	4.18
+SSTRASH	4.97E+04	4.97	1.66E+04	2.37	2.48E+03	.50	2.48E+03	1.04
-LOTRASH	1.40E+04	1.40	7.00E+03	1.00	1.40E+03	.28	1.40E+03	.59
+LOTRASH	1.40E+04	1.40	3.50E+03	.50	3.50E+02	.07	3.50E+02	.15
-PROCESS	2.16E+04	2.16	2.16E+04	3.09	2.16E+04	4.38	2.16E+04	9.10
-PROCESS	7.77E+03	.78	7.77E+03	1.11	7.77E+03	1.57	7.77E+03	3.27
-LOSCNVL	4.08E+04	4.08	3.19E+04	4.56	6.01E+03	1.22	6.01E+03	2.53
+LQSCNVL	4.08E+04	4.08	4.08E+04	5.84	4.08E+04	8.26	4.08E+04	17.16
-ABSLIQD	4.63E+03	.46	2.55E+03	.36	3.09E+03	.63	3.09E+01	.01
+ABSLIQD	4.63E+03	.46	4.63E+03	.66	4.63E+03	.94	4.63E+03	1.95
-BIOWAST	8.34E+03	.83	8.34E+03	1.19	5.79E+02	.12	5.79E+02	.24
+BIOWAST	8.34E+03	.83	8.34E+03	1.19	8.34E+03	1.69	8.34E+03	3.51
-SSWASTE	1.75E+04	1.75	1.75E+04	2.51	1.75E+04	3.55	1.75E+04	7.38
-LOWASTE	1.67E+04	1.67	1.67E+04	2.39	1.67E+04	3.38	1.67E+04	7.01
-NFRCOMP	7.98E+02	.08	7.98E+02	.11	7.98E+02	.16	7.98E+02	.34
-DECONRS	1.93E+04	1.93	1.93E+04	2.77	1.07E+03	.22	1.07E+03	.45
-ISOPROD	1.87E+03	.19	2.87E+03	.41	2.87E+03	.58	2.87E+03	1.21
-HIGHACT	7.21E+02	.07	7.21E+02	.10	7.21E+02	.15	7.21E+02	.30
-TRITIUM	9.63E+02	.10	9.63E+02	.14	9.63E+02	.19	9.63E+02	.41
-SOURCES	5.16E+01	.01	5.16E+01	.01	5.16E+01	.01	5.16E+01	.02
-TARGETS	3.71E+02	.04	3.71E+02	.05	3.71E+02	.08	3.71E+02	.16
OTALS	1.00E+06		6.99E+05		4.94E+05		2.38E+05	

Ground-water impacts, however, are dependent upon the total inventory of radioactive waste delivered to the disposal facility over its 20 year operating life. However, only part of the total inventory is delivered to the disposal facility each year, and radioactive decay reduces the facility inventory during operation. For example, assuming that 1/20 of the total inventory is delivered to the disposal facility each year, then by the time the facility is filled to capacity, the waste delivered the first year will experience 20 years of radioactive decay while the waste delivered the final year will only have decayed one year or less.

To evaluate ground-water impacts, then, it is calculationally convenient to decay the radionuclides in the wastes delivered each year to the end of the operating life of the facility. This produces a total decayed radionuclide inventory which accounts for 20-year time of waste delivery to the disposal facility, and from which a set of decayed "untreated" waste concentrations can be calculated. This is accomplished by taking the projected untreated volumes generated during each year for each waste stream (Table D.9), obtaining the total activity of each radionuclide by multiplying by untreated waste concentrations (Tables D.11 through D.14), multiplying this total activity by an appropriate (radionuclide specific) decay factor, summing these modified total waste stream activities, and dividing this sum by the total untreated waste volumes.

The decayed untreated waste concentrations thus obtained are presented in Tables D.27 through D.30. These decayed untreated concentrations may then be used to determine decayed processed concentrations either on a normalized or regional basis in a similar manner as discussed earlier.

6. <u>OTHER POTENTIAL WASTE STREAMS</u>

This section contains a discussion of waste streams other than the basic streams discussed in Sections 1 through 5 and which: (1) are not currently being sent to LLW disposal facilities, (2) are nonroutine, or (3) are very speculative in terms of timing or waste generation rates. Wastes that fall into this cateory include those from:

- U.S. government operations:
- Decontamination of the Three Mile Island Unit 2 nuclear generating station;
- Transuranic-contaminated wastes, including wastes from potential recycle of nuclear fuel;
- Operations at independent spent fuel storage installations;
- Decommissioning of uranium fuel cycle facilities; and
- Manufacturing process tailings contaminated with low levels of residual uranium and thorium.

These potential waste streams are discussed in the following subsections:

Table D.27 Group 1 Decayed Isotopic Concentrations (Ci/m^3)

	P-IXRESIN	P-CONCLIQ	P-FSLUDGE	P-FCARTG	B-IXRESIN	B-CONCLIQ	B-FSLUDGE
H-3	1.84E-03	2.39E-03	1.79E-03	7.97E-04	1.34E-02	4.35E-04	8.78E-03
C-14	9.73E-05	1.27E-04	9.54E-05	4.25E-05	1.19E-03	3.89E-05	7.77E-04
FE-55	7.30E-04	7.08E-03	9.67E-02	1.73E-01	2.99E-01	2.39E-02	4.54E-01
NI-59	2.79E-06	2.71E-05	3.71E-04	6.60E-04	9.80E-04	7.85E-05	1.49E-03
CO-60	2.17E-03	2.11E-02	2.88E-01	5.14E-01	7.70E-01	6.15E-02	1.17E+00
NI-63	8.15E-04	7.92E-03	1.08E-01	1.93E-01	2.04E-02	1.63E-03	3.08E-02
NB-94	8.84E-08	8.58E-07	1.17E-05	2.09E-05	3.09E-05	2.48E-06	4.70E-05
SR-90	1.63E-04	2.12E-04	1.59E-04	7.07E-05	3.08E-03	9.97E-05	2.00E-03
TC-99	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
I-129	2.44E-06	3.16E-06	2.37E-06	1.06E-06	2.04E-04	6.65E-06	1.33E-04
CS-135	8.23E-07	1.07E-06	8.03E-07	3.58E-07	7.65E-05	2.50E-06	5.00E-05
CS-137	1.86E-02	2.43E-02	1.82E-02	8.12E-03	1.74E+00	5.67E-02	1.13E+00
U-235	4.71E-08	6.15E-08	1.46E-07	3.64E-07	5.33E-08	3.44E-08	3.32E-07
U-238	3.71E-07	4.84E-07	1.15E-06	2.87E-06	4.20E-07	2.71E-07	2.61E-06
NP-237	9.06E-12	1.18E-11	2.81E-11	7.02E-11	1.02E-11	6.61E-12	6.38E-11
PU-238	2.45E-05	4.83E-05	4.49E-05	2.37E-04	7.88E-05	1.88E-04	4.40E-04
PU-239/240	1.82E-05	3.31E-05	1.55E-04	3.80E-04	5.34E-05	9.43E-05	2.36E-04
PU-241	5.63E-04	1.02E-03	4.79E-03	1.18E-02	1.85E-03	3.28E-03	8.20E-03
PU-242	3.99E-08	7.25E-08	3.39E-07	8.34E-07	1.17E-07	2.06E-07	5.18E-07
AM-241	1.85E-05	2.96E-05	2.61E-04	1.62E-04	2.29E-05	1.19E-04	1.54E-04
AM-243	1.26E-06	2.02E-06	1.78E-05	1.10E-05	1.57E-06	8.09E-06	1.05E-05
CM-243	8.52E-09	1.01E-08	2.66E-07	1.66E-07	2.33E-08	2.23E-07	2.56E-07
CM-244	1.06E-05	1.47E-05	1.36E-04	8.44E-05	1.40E-05	1.58E-04	1.72E-04

Table D.28 Group 2 Decayed Isotopic Concentrations (Ci/m³)

	P-COTRASH	P-NCTRASH	B-COTRASH	B-NCTRASH	F-COTRASH	F-NCTRASH	I-COTRASH	N-SSTRASH	N-LOTRASH
H-3	2.11E-04	4.84E-03	4.70E-05	7.60E-03	0.	0.	5.95E-02	0.	1.86E-02
C-14	1.12E-05	2.57E-04	4.17E-06	6.72E-04	0.	0.	5.25E-03	0.	1.64E-03
FE-55	1.86E-03	4.27E-02	1.89E-03	3.05E-01	0.	0.	0.	0.	0.
NI-59	7.11E-06	1.64E-04	6.21E-06	1.00E-03	0.	0.	0.	0.	0.
CO-60	5.52E-03	1.27E-01	4.89E-03	7.84E-01	0.	0.	4.41E-03	0.	1.38E-03
NI-63	2.07E-03	4.78E-02	1.29E-04	2.08E-02	0.	0.	0.	0.	0.
NB-94	2.25E-07	5.18E-06	1.96E-07	3.16E-05	0.	0.	0.	0.	0.
SR-90	1.87E-05	4.30E-04	1.07E-05	1.73E-03	0.	0.	1.19E-03	0.	3.71E-04
TC-99	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	3.39E-09	0.	1.06E-09
I-129	2.78E-07	6.41E-06	7.14E-07	1.15E-04	0.	0.	0.	0.	0.
CS-135	9.42E-08	2.17E-06	2.68E-07	4.33E-05	0.	0.	0.	0.	0.
CS-137	2.14E-03	4.92E-02	6.09E-03	9.81E-01	0.	0.	3.78E-03	0.	1.18E-03
U-235	7.89E-09	1.82E-07	1.22E-09	1.97E-07	1.18E-06	1.13E-06	0.	2.36E-06	0.
U-238	6.22E-08	1.43E-06	9.60E-09	1.55E-06	4.40E-06	4.20E-06	0.	8.80E-06	0.
NP-237	1.52E-12	3.49E-11	2.35E-13	3.78E-11	0.	0.	0.	0.	0.
PU-238	5.64E-06	1.30E-04	2.17E-06	3.51E-04	0.	0.	0.	0.	0.
PU-239/240	5.53E-06	1.27E-04	1.16E-06	1.86E-04	0.	0.	0.	0.	0.
PU-241	1.71E-04	3.93E-03	4.01E-05	6.47E-03	0.	0.	0.	0.	0.
PU-242	1.21E-08	2.79E-07	2.53E-09	4.08E-07	0.	0.	0.	0.	0.
AM-241	3.92E-06	9.02E-05	9.56E-07	1.54E-04	0.	0.	4.76E-06	0.	1.49E-06
AM-243	2.67E-07	6.14E-06	6.51E-08	1.05E-05	0.	0.	0.	0.	0.
CM-243	2.35E-09	5.41E-08	1.66E-09	2.69E-07	0.	0.	0.	0.	0.
CM-244	2.00E-06	4.60E-05	1.15E-06	1.86E-04	0.	0.	0.	0.	0.

Table D.29 Group 3 Decayed Isotopic Concentrations (Ci/m^3)

	F-PROCESS	U-PROCESS	I-LQSCNVL	I-ABSLIQD	I-BIOWAST	N-SSWASTE	N-LOWASTE
H-3	0.	0.	3.27E-03	9.26E-02	1.14E-01	0.	1.06E-02
C-14	0.	0.	2.51E-04	8.15E-03	1.01E-02	0.	9.35E-04
FE-55	0.	0.	0.	0.	0.	0.	0.
NI-59	0.	0.	0.	0.	0.	0.	0.
CO-60	0.	0.	0.	1.32E-02	1.69E-03	0.	6.23E-04
NI-63	0.	0.	0.	0.	0.	0.	0.
NB-94	0.	0.	0.	0.	0.	0.	0.
SR-90	0.	0.	3.55E-03	3.55E-03	6.82E-03	0.	1.07E-03
TC-99	0.	0.	0.	1.02E-08	6.51E-09	0.	7.76E-10
I-129	0.	0.	0.	0.	0.	0.	0.
CS-135	0.	0.	0.	0.	0.	0.	0.
CS-137	0.	0.	0.	1.14E-02	7.26E-03	0.	8.62E-04
U-235	2.30E-05	1.65E-05	0.	0.	0.	4.60E-05	0.
U-238	8.54E-05	3.64E-04	0.	0.	0.	1.71E-04	0.
NP-237	0.	0.	0.	0.	0.	0.	0.
PU-238	0.	0.	0.	0.	0.	0.	0.
PU-239/240	0.	0.	0.	0.	0.	0.	0.
PU-241	0.	0.	0.	0.	0.	0.	0.
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	0.	0.	0.	0.	0.	0.	0.
AM-243	0.	0.	0.	0.	0.	0.	0.
CM-243	0.	0.	0.	0.	0.	0.	0.
CM-244	0.	0.	0.	0.	0.	0.	0.

Table D.30 Group 4 Decayed Isotopic Concentrations (Ci/m³)

	L-NFRCOMP	L-DCONRS	N-ISOPROD	N-HIGHACT	N-TRITIUM	N-SOURCES	N-TARGETS
H-3	0	7.51E-03	2.74E-02	0	1.52E+03	5.63E+02	5.24E+01
C-14	2.59E-01	5.12E-04	4.51E-05	1.32E-02	0	5.75E+01	0
FE-55	6.98E+02	1.27E+01	0	2.97E+01	0	0	0
NI-59	1.40E+00	4.49E-02	0	6.56E-02	0	0	0
CO-60	7.70E+02	3.50E+01	0	3.60E+01	0	7.34E+02	0
NI-63	1.98E+02	3.49E+00	0	9.95E+00	0	2.16E+02	0
NB-94	8.19E-03	1.42E-03	0	4.47E-04	0	0	0
SR-90	0	3.61E-02	5.14E+00	0	0	9.42E+02	0
TC-99	0	1.20E-05	3.27E-04	0	0	0	0
I-129	0	3.34E-05	2.72E-06	0	0	0	0
CS-135	0	1.20E-05	3.27E-04	0	0	0	0
CS-137	0	2.71E-01	7.24E+00	0	0	9.53E+02	0
U-235	0	6.84E-05	1.02E-05	0	0	0	0
U-238	0	5.40E-04	3.81E-05	0	0	0	0
NP-237	0	1.32E-08	5.33E-13	0	0	0	0
PU-238	0	1.26E+00	1.84E-04	0	0	0	0
PU-239/240	0	1.77E+00	5.55E-05	0	0	0	0
PU-241	0	2.52E+01	4.75E-03	0	0	0	0
PU-242	0	3.87E-03	9.57E-08	0	0	0	0
AM-241	0	5.23E-03	1.09E-05	0	0	5.69E+02	0
AM-243	0	3.59E-04	1.25E-06	0	0	0	0
CM-243	0	2.98E-04	1.38E-04	0	0	0	0
CM-244	0	2.51E-03	2.11E-07	0	0	0	0

6.1 U.S. Government Operations

Since the first commercial LLW disposal facilities were opened in 1962 (at Beatty, Nevada and Maxey Flats, Kentucky), considerable volumes of wastes generated by U.S. Government agencies have been shipped to commercial disposal facilities. Most of this waste was produced by laboratories operated by or under contract to the Atomic Energy Commission (AEC). One of the original intents of this practice was to help provide some initial business to the then beginning commercial disposal industry. This practice was continued by the AEC's successors, the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE), until October 1979, when it was discontinued by DOE to help alleviate the shortage in commercial LLW disposal capacity (Ref. 47). Currently, all wastes generated by DOE facilities are disposed in DOE disposal sites. Small quantities of wastes produced by other government agencies such as the Department of Defense (nonclassified waste only) or the U.S. Department of Agriculture, however, are still occasionally shipped to commercial LLW disposal facilities.

6.2 Three Mile Island Unit 2 Decontamination

The March 28, 1979 accident at the Three Mile Island (TMI) Unit 2 nuclear power station has resulted in damage to the reactor core as well as generation of significant quantities of contaminated water. Removal of damaged core components and other plant equipment, processing of the contaminated water, and decontamination of contaminated plant equipment and surfaces is projected to take about 5 to 9 years. Over this time period, radioactive wastes in various solid forms will be generated. NRC has prepared and published a programmatic environmental impact statement (PEIS) related to decontamination and disposal of radioactive wastes resulting from the accident (NUREG-0683, Ref. 48). In this document, NRC staff investigated a wide variety of decontamination and waste processing alternatives. Bounding (probable minimum and probable maximum) volumes of wastes projected to be delivered to LLW disposal facilities as a result of these decontamination operations and waste processing alternatives have been set out in the PEIS. A summary of these projections excerpted from the PEIS is included in this appendix as Table D.31.

The range in projected volumes reflects the fact that the actual volumes of waste generated will depend upon decisions regarding which decontamination and waste treatment alternatives are implemented. In many cases, such decisions will be made as the decontamination operations progress.

The decontamination and waste treatment operations will also generate some volumes of waste that will not be disposed at near-surface disposal facilities. These include fuel or pieces of fuel removed from the reactor, other transuranic-contaminated wastes (if generated), and some very high specific activity ion-exchange media wastes generated as a result of treating contaminated reactor building water.

6.3 Generation of Transuranic-Contaminated Waste

This section discusses the past and potential future generation and disposal of waste containing or contaminated with transuranic radioisotopes (isotopes

Table D.31 Volumes of TMI-2 Packaged Solid Waste to be Disposed of at a Commercial Low-Level Waste Disposal Site

Type of Package	Package Volume (ft^3)	Best-Case Conditions: Number of Packages	Best-Case Conditions: Shipped Volume (ft^3)	Worst-Case Conditions: Number of Packages	Worst-Case Conditions: Shippe Volume (ft^3)
55-Gallon Drums					
Low activity	7.5	3,200	24,000	15,400	115,50
Intermediate activity	7.5	502	3,765	1,707	12,80
LSA Boxes*					
Low activity	80	1,042	83,360	2,128	170,24
Contaminated Equipment	70	86	6,020	293	20,51
and Hardware, Mirror Insulation	80	53	4,240	-	-
EPICOR II Resins					
1st stage**	50	49	2,450	49	2,45
2nd stage	50	14	700	14	70
3rd stage	175	6	1,050	6	1,05
Reactor Building Cleanup					
Filters†	10	11	110	11	11
2nd stage	50	2	100	4	20
3rd stage	190	1	190	2	38
Primary System Cleanup†					
Filters††	10/7.5/150	16	990	57	1,34
2nd stage	50	4	200	44	2,20
3rd stage	190	3	570	12	2,28
Total		128,260			329,76

*Low specific activity.

**Will require special disposal procedures (e.g., deeper burial) if disposed of at a commercial disposal site.

†If any of these wastes contain fuel debris or greater than 10 nCi/gm transurani materials, they would not be accepted at a commercial LLW facility.

††Primary system cleanup generated 3 filter types.

having atomic numbers greater than that of uranium, which has an atomic number of 92). To put this discussion into perspective, however, a brief backround is needed regarding past and probable future government disposal policies toward TRU waste.

Background

At one time, transuranic waste was disposed at near-surface disposal facilities operated by the AEC in addition to 5 of the 6 commerical disposal facilities. However, in 1970, the AEC initiated a policy whereby most government-produced waste containing TRU isotopes in concentrations greater than 10 nanocuries per gram of waste material were placed into retrievable storage pending transfer to a repository for ultimate disposal. The 10 nanocurie per gram limit was based upon rough comparison with the potential hazards of upper concentration levels of naturally occurring radium in the earth's crust. However, TRU waste generated as a result of AEC (and later DOE) contracts with private contractors (and some DOE prime contractors) was still sent to commercial disposal facilities

Retrievable storage of commercially-generated TRU waste (pending development of an ultimate repository of the waste) by the Federal government was the intent of a rule proposed in 1974 (Ref. 47). Under this rule, commercial TRU waste would have been consigned to retrievable storage facilities operated by the federal government pending the development of a facility for the ultimate disposition of the waste. A sensitivity level of 10 nanocuries per gram was proposed for measurements to determine the presence or absence of TRU contamination. At the time of the proposed rule, it was expected that commercial recycle of plutonium mixed oxide (MOX) fuel for use in breeder reactors and in light-water reactors would greatly increase in the near future. It was expected that significant additional volumes and quantities of TRU waste material would therefore soon be generated.

Persons commenting on the 1974 proposed rule were generally favorable to the overall concept that the Federal Government should accept title to high-level and transuranium waste and be responsible for its subsequent storage, treatment, and disposal. The draft environmental impact statement (Ref. 50) that was published to support the proposed TRU rule was withdrawn by the Energy Research and Development Administration (ERDA) when the AEC was reorganized to form ERDA and NRC. Also, the AEC's General Manager did not produce the packaging requirements and a schedule of fees necessary for its implementation. The 1974 proposed rule was consequently not adopted by NRC. On the other hand, the retrievable storage policy adopted for government-produced TRU waste is still in effect at sites operated by the Department of Energy (DOE), the successor organization to ERDA.

Individual state initiatives have resulted in a 10 nanocurie per gram disposal limit for TRU waste at all operating commercial low-level waste disposal facilities. Although at one time, five of the six commercial LLW disposal sites accepted TRU waste for disposal (the Barnwell, South Carolina facility has never accepted TRU waste for disposal), this practice has been discontinued. The last commercial facility to accept TRU waste for disposal was the facility located in the center of the Hanford Reservation near Richland, Washington and operated by the Nuclear Engineering Company (NECO) (now U.S. Ecology, Inc.). From 1976 to 1979, the NECO-Richland facility was the only commercial disposal facility accepting TRU waste for disposal. TRU waste acceptance at the NECO-Richland facility in concentrations exceeding 10 nCi/gm was prohibited by the state of Washington in November 1979 (Ref. 43).

In November 1979, the NRC requested that DOE finalize and implement its plans for routine acceptance of commercial TRU waste for retrievable storage pending disposal into a repository (Ref. 51). These plans have been under development by both DOE and its predecessor, the Energy Research and Development Administration and AEC. NRC requested DOE to provide NRC with details on technical criteria for TRU waste storage, including waste form and content, packaging and storage charges. DOE responded that it was their view that they do not have legal authority to accept commercial TRU waste for storage. As a result of the foregoing, there is no means for long-term storage or disposal of TRU waste available to commercial generators. Each licensee must provide his own storage for an indeterminate time.

TRU Waste Generation

Compared to operations conducted by the Department of Energy (DOE), there has been only relatively small quantities of transuranic (TRU) waste generated by the commercial sector. Major sources of transuranic wastes that have been delivered in the past to commercial disposal facilities have included waste from:

- DOE and its successors, the Energy Research and Development Administration (ERDA) and the Atomic Energy Commission (AEC);
- DOE, ERDA, and AEC contractors;
- Reprocessing of spent uranium fuel at the West Valley, New York commercial fuel reprocessing plant.
- Research and development of plutonium fuels, including fabrication of small quantities of mixed-oxide (MOX) fuels for test purposes in light water reactors; and
- Research studies of irradiated reactor fuel.

Within the last few years, the amount of transuranic waste delivered to commerci disposal facilities has been further reduced to even lower levels and has been finally discontinued. This has been caused by a number of factors. One factor was the policy announced by AEC in 1970 whereby AEC-produced TRU waste in concentrations greater than 10 nCi/gm were consigned to retrievable storage at AEC facilities pending the availability of a repository for the ultimate disposition of the waste. TRU waste generated as a result of AEC (and later DOE) contracts with private companies, however, was still sent to commercial disposal sites. The only commercial reprocessing facility ever to operate in the United States was the facility operated by Nuclear Fuel Services (NFS) near West Valley, New York. In 1972, this facility was shut down and has not operated since. In 1976, President Carter announced a national policy of deferment of commercial fuel reprocessing. This poilcy of deferring fuel reprocessing has halted most of the mixed oxide fuel research and development work in the commercial sector. Prior to the cutoff of TRU disposal at the NECO-Richland site, most commercial mixed oxide fuel fabrication test facilities had an active program underway for facility clean-up and decontamination.

Table D.32 is a summary of the quantities of plutonium delivered to the NECO-Richland site during the years 1976 through 1978, and the year 1979 to May 24 (Ref. 18). Most of the TRU waste generated was from clean-up and decontamination of former plutonium research laboratories and small-scale MOX fuel fabrication facilities. Small quantities of waste (e.g., Battelle Columbus Laboratory) were also generated from burn-up studies of LWR fuel. Not shown on this table are some very small quantities of wastes contaminated with Pu-238 (estimated at less than 5.7 m^3/year) and produced from the manufacture of radioactive power sources. Significant quantities of TRU waste shipped to the NECO-Richland site during this time period were owned by DOE--i.e., 75% in 1976, 31% in 1977, 25% in 1978, and 69% in 1979 up to May 24. Much of the other plutonium contaminated wastes--even if not directly owned by DOE--were generated as a direct result of DOE-contracted work.

Future generation of TRU waste is speculative but may arise from three basic sources: decontamination of existing small scale plutonium research and fuel fabrication facilities, studies of irradiated LWR fuel, and recycle of spent uranium fuel. Based on information received by NRC staff from industry and DOE, it appears that decontamination of existing plutonium fuel fabrication facilities would generate approximately 4960 m^3 of waste over an approximate 3-year time period. These wastes are expected to have low radiation levels permitting contact handling of waste packages. Following these decontamination and decommissioning activities, potential TRU waste volumes are projected to drop to low levels (approximately 75 m^3) (Ref. 52), and would result primarily from destructive examination of reactor fuels. These wastes are expected to have high-surface radiation levels and would require remote handling. Plutonium-238 contaminated waste from manufacture of heat sources would also be expected to continue at a rate of about 5.7 m^3 per year. Of course, the current prohibition of commercial TRU disposal combined with the DOE position on TRU waste acceptance has a great effect on the timing of the generation of such waste. Any waste generated would have to be stored onsite.

Finally, significant quantities of TRU waste could be generated in the future through implementation of a plutonium-based nuclear fuel cycle--that is, through reprocessing of irradiated LWR fuel to extract residual fissile uranium and plutonium and through fabricating the received uranium and plutonium into mixed oxide fuel for reuse in LWRs. Potential volumes and activities of wastes that would be generated by uranium recycle operations have been estimated by a number of groups, including NRC (Ref. 2), DOE (Ref. 54), and the national laboratories, (Refs. 55, 56). Most of the waste thus generated would be contaminated with (or suspected of being contaminated with) transuranic isotopes and would not be acceptable at current operating disposal facilities.

Table D.32 Grams of Plutonium Delivered to NECO-Richland Disposal Facility Between 1/1/76 and 5/24/79

	1979	1978	1977	1976
Babcock and Wilcox Lynchburg, VA	52 (J)	270 (J)	35 (J)	--
Babcock and Wilcox Leechburg, PA	--	27 (G)	414 (J)	7074 (B) 630 (G) 945 (J)
Westinghouse Cheswick, PA	--	152 (G)	222 (G)	273 (G)
General Electric Vallecitos, CA	350 (G)	1006 (G) 2268 (J)	120 (J) 810 (J)	117 (J)
Battelle Columbus, OH	29 (G) 98 (H)	22 (G) 18 (H) 268 (J)	--	--
Battelle (PNL) Richland, WA	--	--	10 (G) 113 (J)	21 (J)
Kerr-McGee Cimmaron, OK	--	77 (J)	49 (J)	1798 (B) 474 (J)
Nuclear Fuel Services Erwin, TN	--	594 (J)	--	76 (J)
Allied General Nuclear Services Barnwell, SC	--	20 (J)	--	--
US Army Material Command	--	--	--	1 (B)
Lovelace Foundation, Albq. NM	--	--	*	*
LFE Environmental, Rich., CA	--	*	*	--
General Atomic Company San Diego, CA	--	--	--	*
Total	529	4870	2242	12330
(B)	-	--	--	--
(G)	379	1207	701	8873
(H)	98	18	--	988
(J)	52	3645	1541	2489
% of Total: (B) + (G)	90%	25%	31%	75%
% of Total: (H) + (J)	10%	75%	69%	75%

(B) DOE-Owned, Lease Agreement - Nonwaiver of Use Charge.
(G) DOE-Owned Production and Research Programs.
(H) Owned by Ohter U.S. Government Agencies.
(J) Privately Owned (Domestic).
*Less than 1 gram.
**To 5/24/79.

In any case, the timing of the generation of such waste is very speculative. The current policy of the United States is to defer processing of spent light-water reactor fuel. Spent uranium fuel removed from nuclear power reactors is presently stored without attempting to extract the residual fissile uranium and plutonium for use. Even if the national policy regarding recyle of uranium fuel were to change within a short time period, it would still be several years before significant quantities of wastes would be produced. Of the three commercial reprocessing plants that have been constructed in the United States--that is, at West Valley, New York, Morris, llinois, and Barnwell, South Carolina--only the West Valley plant has ever operated. This plant, however, has not operated since 1972. None of the three facilities could operate today without some modification. Of the three, the Barnwell facility would require the least construction--principally construction of a waste solidification facility, a facility for conversion of liquid plutonium nitrate to solid plutonium oxide, and probable installation of additional airborne effluent treatment systems. The Morris facility would require major changes in the design of the processing operations. The West Valley plant would require considerable modification to meet seismic and radiation shielding requirements. In addition, the operator of the West Valley plant--Nuclear Fuel Services, Inc.--has previously (in 1976) expressed a desire not to continue in the reprocessing business.

There are currently no large-scale commercial facilities for fabrication of mixed-oxide fuel, although a number of small scale commercial laboratories and research facilities are in existence that have in the past fabricated small batches of MOX fuel for experimental use in LWRs. Such large scale facilities would have to be constructed if extensive recycle activities were to proceed.

Finally, there are a number of institutional considerations. Licensing for construction of new uranium recycle facilities or modification of old ones would be required. Such licensing would include regulatory review, publication of environmental impact statements and other environmental assessments, and possible hearings. DOE would have to finalize and implement plans for acceptance of TRU and high-level waste for retrievable storage pending disposal into a repository. The costs for such retrievable storage have not been developed by DOE and, as discussed earlier, DOE has taken the position that it does not have legal authority to accept commerical TRU waste for storage. In addition, no final decision has been made regarding criteria for high-level and TRU waste form characteristics for disposal.

6.4 <u>Independent Spent Fuel Storage Facilities</u>

As there is at this time neither an ongoing nuclear fuel reprocessing industry or a federal high-level waste repository, spent nuclear fuel removed from nuclear power plants must be safely stored. This spent fuel is currently being stored in fuel pools located within nuclear power stations as well as within two facilities originally designed to process the spent fuel: the General Electric (GE) reprocessing plant located near Morris, Illinois, and the Nuclear Fuel Servces (NFS) reprocessing plant located near West Valley, New York. The GE facility never became operational and the NFS facility suspended reprocessing operations in 1971. As of the end of 1979, the total amount of spent fuel stored in the Morris and West Valley plants corresponded to about 9 percent of the total U.S. commercial inventory of stored LWR fuel (Ref. 58).

The existing storage capacity for spent LWR fuel is not likely to be adequate until a repository or an ongoing fuel reprocessing industry is developed. Additional storage capacity has been provided through fuel storage densification in existing fuel storage pools. Alternatives that may be used to provide needed additional storage capacity in the future include construction of new pools at power plants, expansion of storage capacity in the West Valley and Morris facilities, use of the fuel storage capacity of the uncompleted Barnwell, South Carolina reprocessing plant, or construction of new independent spent fuel storage facilities. Dry storage concepts for aged spent fuel are also being developed and are of interest for use at either reactor sites or away-from-reactor independent storage facilities. Recently, NRC published a new set of regulations, 10 CFR Part 72, that established rules for licensing independent spent fuel storage facilities, if and when they are constructed (Ref. 49).

Wastes from storing spent LWR fuel would primarily arise from treatment of the storage basin water, receiving and unloading spent fuel, and plant ventilation systems. These wastes include spent resins, filter sludges and miscellaneous trash, and are similar in composition to wastes produced from other light-water reactor operations.

Waste volumes generated to the year 2000 from LWR spent fuel storage are expected to be relatively small. Most of the waste volumes generated would continue to be included with other wastes shipped from power plants. Only small quantities of wastes are produced by the current two facilities practicing away-from-reactor storage. LLW generated at the West Valley plant is disposed onsite at the colocated LLW disposal site. At the Morris plant, low specific activity trash is currently shipped to an LLW disposal site. Liquid wastes and filter sludges generated from backflushing and regenerating the fuel pool water filter system are stored in a large (2.6 million liter capacity) low activity waste (LAW) tank. The LAW tank was originally constructed and intended to store low-level liquids generated during the operation of the reprocessing plant. Eventually, General Electric plans to install a solidification system to solidify the liquids and other wet wastes and send the solidified waste material to an LLW disposal facility (Ref. 59).

DOE has developed an estimate of the annual volumes of waste that could be generated from a large (3000 MTHM) independent spent fuel storage installation, assuming that one is constructed (Ref. 54). These volumes are listed in Table D.33 and are based upon a conservative (in terms of waste generation) assumption of an operating mode in which one-sixth of the storage capacity is replaced each year. The total volume of waste produced from such a large facility is comparable to the annual generation rate of a single 1000 MW(e) light water reactor.

At this time, NRC has not received any application for construction and operation of an independent spent fuel storage facility. The timing for future construction of a storage facility (and associated waste volume generation) is speculative.

6.5 Decommissioning of Nuclear Fuel Cycle Facilities

Nuclear fuel cycle facilities will eventually reach the end of their useful lives and would then be considered candidates for decontamination and decommissioning.

Table D.33 Estimated Annual Waste Volumes Generated from Assumed Operation of a 3,000 MTHM Spent Fuel Storage Facility

Waste Category	Volume (m^3)
Compactible and Combustible Wastes	
Combustible trash	630
Ventilation filters	23
Liquids and Other Wet Wastes	
Bead resins	2
Filter precoat sludge	8
Sulfate concentrate	7
Miscellaneous solution concentrates	10
Noncombustible material	
Noncombustible trash	51
Failed equipment	19
Total	750

In some cases, decontamination and decommissioning activities may merely involve removing enough residual contamination to allow safe modification and reuse as a nuclear facility. In other cases, the facility may be decontaminated to the point that it can be released for unrestricted use.

The timing and extent of potential decontamination and decommissioning activities at a nuclear installation are believed to be speculative at this time. The timing and extent of decommissioning activities may depend upon other factors than the useful life of a nuclear facility--e.g, upon economic decisions or regulatory requirements. It is considered unlikely that significant volumes of wastes from decommissioning nuclear fuel cycle facilities will be produced prior to the year 2000. Nonetheless, NRC staff has investigated the potential volumes, activities, and other characterisitics of wastes generated from decommissioning of a number of different types of nuclear fuel cycle facilities, and these volumes and activities can be briefly investigated to help gauge the potential impacts of future waste streams. Waste streams considered include those generated from decommissioning: (1) light water reactors, (2) uranium fuel fabrication plants, and (3) uranium fuel recycle facilities.

6.5.1 Decommissioning of Light Water Reactors

A significant source of waste to be generated in the future will be from decommissioning light water power reactors. The volumes and activities which will be produced are speculative to a high degree, and will depend upon such factors as the length of service life of a plant prior to decommissioning, the size and design of a plant, the operating history of the plant, and the decommissioning mode undertaken (e.g., immediate dismantlement after shutdown vs. deferring dismantlement for up to several years following shutdown).

Pacific Northwest Laboratories (PNL) has recently completed a pair of studies on the technology safety, and costs of decommissioning a large reference PWR (Ref. 33) and a large reference BWR (Ref. 60). The model for the reference PWR is the Portland General Electric Company Trojan Nuclear plant having a generating capacity of 1175 mW(e) (3500 MW(t)), and using a Westinghouse four-loop nuclear steam supply system. The model for the reference BWR is the Washington Public Power System's Nuclear Project No. 2 (WPPSS-2) at Hanford, Washington. This 1155 MW(e) unit (3320 MW(t)), which is expected to start operation in 1982, uses a General Electric BWR-5 nuclear steam supply system. The plant uses a Mark-II containment.

A summary of the waste volumes and activities estimated by PNL for the two reference LWRs is provided in Table D-34. The volumes and activities are projected from an assumption of immediate dismantlement of the plant following 40 calendar years of operation at 75% of full power, or 30 effective full power years (EFPY). Dismantlement of the reference PWR is projected to require 4 years, while dismantlement of the reference BWR is projected to require 3-1/2 years.

The volumes and activities summarized in Table D-34 should be should be interpreted with some care. Actual volumes and activities from decommissioning a given LWR may be highly site specific and a function of such factors as the size and design of the unit, the rated power level, the amount of time spent at full power, and the time between shutdown and dismantlement. However, it is apparent that on the order of 99% of the activity from decommissioning wastes will be contained in activated metal. Relative volumes and activities for various activated metal components are shown in Table D-35. As shown, specific activities of BWR activated components are estimated to vary by four orders of magnitude, while PWR components by six orders of magnitude. Of special interest for disposal purposes are the BWR core shroud and the PWR core should and lower grid plate.

NRC staff does not expect that volumes and activities of decommissioning wastes generated to the year 2000 will be significant compared to other routinely generated LWR waste streams. In any case, the characteristics of actual waste generated from a particular LWR would be analyzed as part of a decommissioning environmental impact statement prepared for that facility. The volumes and activities estimated by PNL are for large modern units and such units are not expected to undergo decommissioning until well after the year 2000. Reactors potentially dismantled prior to the year 2000 are expected to be considerably smaller in capacity, have shorter operating lives than the reactors used as models for the PNL studies and are expected to generate considerably lower waste volumes and/or activites.

Table D.34 Summary of Wastes From Decommissioning a Reference PWR and a Reference BWR

Waste Stream	Volume (m^3)	Activity (Ci)
Reference 1155 MW(e) BWR:		
Activated metal	138	6,552,310
Activated concrete	90	170
Contaminated metal	15,543	8,574
Contaminated concrete	1,676	55
Dry solid waste (trash)*	3,386	--
Spent resins	42	228
Filter cartridges†	--	--
Evaporator bottoms††	519	43,753
Reference 1175 MW(e) PWR:		
Activated metal	418	4,841,230
Activated concrete	707	2,000
Contaminated metal	5,465	900
Contaminated concrete	10,613	100
Dry solid waste (trash)*	1,418	--
Spent resins**	30	42,000
Filter cartridges†	8.9	5,000
Evaporator bottoms††	133	--

*Volumes shown are as generated and prior to additional treatment such as compaction or incineration. Most of the trash is considered to be combustible.

**BWR spent resins actually include spent resins and filter sludge. Volumes shown are dewatered volumes.

† PWR filter cartridge volumes are as solidified in concrete in 55-gallon drums. Filter cartridges are assumed not to be used in the BWR wet waste treatment system.

††PWR and BWR evaporator bottom volumes are as generated prior to solidification.

Table D.35 Volumes and Activities of Decommissioned LWR Activated Metals

Component	Disposal Volume (m^3)*	Activity Ci	Specific Activity (Ci/m^3)
Reference BWR:			
Steam separator assembly	10	9,600	960
Fuel support pieces	5	700	140
Control rods and in-core instruments	15	189,000	12,600
Control rod guide tubes	4	100	25
Jet pump assemblies	14	20,000	1,429
Top fuel guide	24	30,100	1,254
Core support plate	11	650	59
Core shroud	47	6,300,000	134,043
Reactor vessel wall	8	2,160	46
Total	138	6,552,310	
Reference PWR:			
Pressure vessel cylindrical wall	108	19,170	178
Vessel head	57	<10	.18
Vessel bottom	57	<10	.18
Upper core	11	<10	.91
Support assembly			
Upper support columns	11	<100	9.1
Upper core barrel	6	<1,000	167
Upper core grid plate	14	24,310	1,736
Guide tubes	17	<100	6
Lower core barrel	91	651,000	7,154
Thermal shields	17	146,100	8,594
Core shroud	11	3,431,100	311,909
Lower grid plate	14	553,400	39,529
Lower support columns	3	10,000	333
Lower core forging	31	2,500	81
Miscellaneous internals	23	2,000	87
Reactor cavity liner	15	<10	.7
Total	485	4,841,320	

*Disposal volumes include the disposal container after the activated metal components have been cut into manageable pieces.

There are a number of early low power units generally constructed as demonstration projects forerunning larger, more economical to operate units with capacities on the order of several hundred to a thousand MW(e). Although utilities would generally prefer to keep the older units operable for as long as they are cost-effective, costs of upgrading the older units to meet new NRC safety requirements may result in some of the older plants being decommissioned prior to the year 2000, and prior to the end of their otherwise servicable lives.

A specific example is the Indian Point Unit 1 plant located near Buchanan, New York. This 175 MW(e) (600 MW(t)) PWR was shut down in October 1974 by its utility, Consolidated Edison, due to inability to meet new NRC requirements on emergency core cooling systems (ECCS). Consolidated Edison has recently determined that the cost of upgrading the plant to meet the new ECCS and other requirements would be greatly in excess of the possible economic gain, and have announced their intention of decommissioning the unit. The proposed timing and mode of decommissioning (safe storage, immediate dismantlement, or deferred dismantlement) however, has not yet been finalized.

6.5.2 Decommissioning of Uranium Fuel Fabrication Plants

A relatively minor source of decommissioning waste, compared to decommissioning light water reactors, will be wastes from decommissioning uranium fuel fabrication facilities. Potential waste volumes from decommissioning a relatively large fuel fabrication facility plant have been estimated by Pacific Northwest Laboratories (PNL) (Ref. 61), and estimates based upon this study are summarized in Table D.36. In the PNL study, a model plant is assumed that is based upon an existing facility operated by the General Electric Company in Wilmington, North Carolina. The plant is assumed to be operated for 40 years at a production rate of 1000 metric tons of uranium oxide fuel per year. Feed to the plant is enriched UF_6. All of the calcium flouride (CaF,) wastes and other conversion process sludges that are generated during the process converting UF_6 to UO_2, are assumed to be stored onsite in large lagoons until decommissioning.

As shown in Table D.36, the calculated volumes of wastes generated from decommissioning the plant include trash and other miscellaneous material from decontaminating buildings and other facilities, as well as several thousand cubic meters of low activity bulk solid material such as CaF_2. The total quantity of uranium contained in the 1091 m^3 of miscellaneous trash is projected by PNL to be approximately 270 kg. The concentration of uranium in the 27,000 m^3 of low activity material is expected to be low.

These estimated quantities should be used with some care. For example, the timing of future fuel fabrication plant decommissioning activities is very speculative, and would probably depend more on economic than safety considerations. Although the amount of fuel fabrication capacity would naturally be a function of nuclear power plant capacity, the total potential decommissioning volume would not be expected to be a strong function of capacity. Rather, total volumes of waste material obtained from decommissioning fuel fabrication plants would be more of a function of the number of plants operating and the design of individual plants rather than a function of the total throughput of uranium feed through the plants.

Table D.36 Waste Volumes Generated From Decommissioning a Model 1000 MT UO_2/yr Fuel Fabrication Plant

Wastes from decommissioning buildings and other site structures:

Waste Category	Volume m³)
Hoods, equipment and components	764.4
Pipe, conduit, duct, trays, fixtures, etc.	118.52
HEPA and roughing filters	51.66
Concrete rubble	39.66
Contaminated liner and soil materials	91.0
Miscellaneous	25
Total	1,091

Low-activity bulk solids:

Waste Category	Volume (m^3)
Chemical sludge	1,282
Contaminated CaF_2	25,296
Other miscellaneous contaminated material	3,206
Total	29,784

Projected volumes of CaF_2, and other chemical sludges produced from UF_6 conversion are also speculative. The rate of production of UF_6 conversion sludges at a facility is a strong function of the design of the conversion process used at the facility. Space limitations at an individual plant may result in process sludges being transferred to LLW disposal facilities during plant operation rather than being left onsite in lagoons for later consideration. Existing and future sludge lagoons at fabrication facilities may, rather than being collected and delivered to an LLW disposal facility during decommissioning, be disposed in-place or treated to recover the contained uranium.

6.5.3 Decommissioning Uranium Fuel Recycle Facilities

Should uranium recycling be eventually adopted as a national policy, then uranium recycle facilities that would be constructed would eventually require decommissioning. Such decommissioning activities would occur relatively remote from today--at least beyond the year 2000. Volumes and activities of wastes that would result in decommissioning some reference uranium fuel recycle facilities have been estimated by PNL. In NUREG-0278 (Ref. 61), the technology, safety, and costs of decommissioning a 1500 MTHM/year fuel reprocessing plant are assessed, using the uncompleted Barnwell, South Carolina reprocessing plant owned by Allied-General Nuclear Services as a model (Ref. 62). In NUREG/CR-0129 (Ref. 63), the technology, safety and costs of decommissioning a small mixed-oxide fuel fabrication plant are assessed.

A potential source of wastes that may be generated in the next few years would be from decommissioning the Nuclear Fuel Services (NFS) reprocessing plant located in West Valley, New York. The reprocessing plant has not operated since 1972 and NFS announced in 1976 their intention to withdraw from the nuclear fuel reprocessing business. The eventual disposition of the facility, which includes a fuel reprocessing plant, 600,000 gallons of liquid high-level waste stored in a tank, and a waste disposal area, is being addressed at this time. Fairly recently, DOE published a report that addressses alternatives for eventual disposition of the site, including full or partial decommissioning or continued use as some manner of nuclear production or research facility (Ref. 57). After completion of this study of alternatives, which was mandated by Congress, legislation was passed in 1980 (The West Valley Demonstration Project Act) that charges DOE with the responsibility to develop, construct, and operate a high-level liquid waste solidification project at the West Valley plant. This project will solidify the 600,000 gallons of liquid high-level waste presently stored in underground tanks to a final form acceptable for disposal into a federal repository. Decontamination of existing facilities to prepare for the project as well as activities during the waste solidification project and final decontamination of facilities at the end of the project will generate substantial volumes of low-level waste. Much if not most of this waste is expected to be contaminated with transuranic radionuclides. DOE has not yet determined where these wastes will be disposed, but it appears that most of it will be consigned to a federal (DOE) disposal area.

REFERENCES

1. South Carolina Department of Health and Environmental Control, Radioactive Material License No. 097, Amendment No. 28, November 13, 1980.

2. U.S. Nuclear Regulatory Commission, Final Generic Environmental Statement o the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactor, NUREG-0002, August 1976.

3. U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Stat ment on Uranium Milling, NUREG-0706, September 1980.

4. Personal communication form George Kuzmych, NRC project manager for Ft. St Vrain, to G. W. Roles, US NRC, May 29-30, 1980.

5. Wild, R.E., et al., Data Base for Radioactive Waste Management. Volume 2. Waste Source Options, NUREG/CR-1759, being prepared by Dames & Moore for NRC, to be published.

6. Phillips, J., et al., A Waste Inventory Report for Reactor and Fuel Fabrication Facility Wastes, ONWI-20, prepared by NUS Corporation for Battelle. Office of Nuclear Waste Isolation, March 1979.

7. Anderson, R. L., et al., Institutional Radioactive Waste, prepared by University of Maryland for the U.S. Nuclear Regulatory Commission, NUREG/CR-0028, March 1978.

8. Beck, T. J., L. R., Cooley, and M. R. McCambell, Institutional Radioactive Wastes, 1977, NUREG/CR-1137, Prepared by University of Maryland, October 1979.

9. U.S. Department of Energy, Nuclear Reactors Built, Being Built, or Planned in the United States as of June 30, 1979, DOE/TIC-8200-R40, DOE Technical Information Center, 1979.

10. Department of Energy, Nuclear Reactors Built, Being Built, or Planned in the United States as of December 31, 1979, DOE/TIC-8200-R41, DOE Technical Information Center, 1980.

11. Nuclear News, World List of Nuclear Power Plants Operable, Under Construction, or on Order (30 MWe and over) as of June 30, 1980, Nuclear News, Vol. 23, No. 2, February 1980.

12. Nuclear News, World List of Nuclear Power Plants Operable, Under Construction, or on Order (30 MWe and over) as of June 30, 1980, Nuclear News, Vol. 23, No. 10, August 1980.

13. Personal communication from W. Lovelace, NRC Office of Management and Program Analysis, to G. W. Roles, NRC, August 21, 1980.

14. U.S. NRC Staff, Low-Level Waste Licensing Branch, Projections of Routinely Generated Low-Level Radioactive Waste Through the Year 2000, December 1980.

15. U.S. NRC, Final Environmental Statement Related to Primary Cooling System Chemical Decontamination at Dresden Nuclear Power Station, Unit No. 1, Docket No. 50-10, NUREG-0686, October 1980.

16. Bishop, C., U.S. Nuclear Regulatory Commission letter to R. E. Wild, Dames & Moore, June 2, 1980.

17. Roché-Farmer, L., Study of Alternative Methods for the Management of Liquid Scintillation Connecting Wastes, NUREG-0656, February 1980.

18. Bell, M. J., Oak Ridge National Laboratory, ORIGEN - The ORNL Isotope Generation and Depletion Code, ORNL-4628, Oak Ridge National Laboratory Report, May 1973.

19. U.S. Nuclear Regulatory Commission, Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Boiling Water Reactors (BWR-GALE Code), NUREG-0016, 1976.

20. U.S. Nuclear Regulatory Commission, Calculation of Releases of Radioactive Materials in Gaseous Liquid Effluents from Pressurized Water Reactors (PWR-GALE Code), NUREG-0017, 1976.

21. Cooley, L. R., University of Maryland, letter to J. C. Clancy, Dames & Moore, Estimated Activity Concentrations of Institutional Radwastes, March 19, 1980.

22. Cline, J. E., and D. C. Hetzer, Study of Transuranic Concentration Levels in Solid Radioactive Waste from Commercial Power Reactors, NP-631, prepared by Science Applications, Inc. for the Electric Power Research Institute, January 1978.

23. Cline, J. E., et al., Activity Levels of Transuranic Nuclides in Low-Level Solid Wastes from U.S. Power Reactors, NP-1052, prepared by Science Applications, Inc. for the Electric Power Research Institute, April 1979.

24. Cline, J. E., et al., Activity Levels of Transuranic Nuclides in Low-Level Solid Wastes from U.S. Power Reactors, NP-1494, prepared by Science Applications, Inc. for the Electric Power Research Institute, August 1981.

25. Dames & Moore, Characterization of Selected Low-Level Radioactive Waste Generated by Four Commercial Light-Water Reactors, ORP/TAD-77-3, prepared for U.S. Environmental Protection Agency, 1977.

26. Zima, G. E., Comments on Fuel Crud as a Safety and Operational Factor of Independent Spent Fuel Storage Installations (ISFSI), NUREG/CR-0163, prepared by Battelle Pacific Northwest Laboratories for the U.S. Nuclear Regulatory Commission, November 1978.

27. Smith, R. D., U.S. Nuclear Regulatory Commission, memorandum to J. B. Martin, USNRC, Low-Level Waste Activity and Volume Estimates for 1979, August 10, 1979.

28. Sears, M. B., et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle--Conversion of Yellow Cake to Uranium Hexa-fluoride. Part 1. The Fluorination-Fractionation Process, ORNL/NUREG/TM-7, prepared by Oak Ridge National Laboratory for NRC, September 1977.

29. Cooley, L. R., University of Maryland, personal communication to O. Oztunali, Dames & Moore, April 1980.

30. Finney, B. C., et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle--Reprocessing Light-Water Reactor Fuel, ORNL/NUREG/TM-6, prepared by Oak Ridge National Laboratory for NRC, January 1977.

31. Smith, R. I., G. J. Konzek, and W. E. Kennedy, Jr., Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, NUREG/CR-0130, prepared by Battelle Pacific Northwest Laboratories for NRC June 1978.

32. Technekron, Inc., Volume Reduction Techniques in Low-Level Radioactive Waste Management, being prepared for NRC.

33. Godbee, H. W., and A. H. Kibby, The Use of Evaporation to Treat Radioactive Liquids in Light-Water Cooled Nuclear Reactor Power Plants, NUREG/CR-0142, prepared by Oak Ridge National Laboratory for U.S. NRC, September 1978.

34. Aerojet Energy Conversion Company, Radioactive Waste Volume Reduction System, Topical Report No. AECC-2-NP, prepared for U.S. NRC, October 15, 1979.

35. Newport News Industrial Corporation, RWR-1™ Radwaste Volume Reduction System, Topical Report No. EI/NNI-77-7-NP, prepared for NRC, June 24, 1977.

36. United Technologies, Chemical Systems Division, Inert Carrier Radwaste Process, May 1979.

37. Bond, R. G., and C. P. Staub, eds., Handbook of Environmental Control, Volume II: Solid Waste, CRC Press, Cleveland, Ohio, 1973.

38. Premuzic, E. T. and H. K. Manaktala, Scoping Study of the Alternatives for Managing Waste Containing Chelating Decontamination Chemicals, BNL-NUREG-28403, informal report prepared by Brookhaven National Laboratory for NRC, September 1980.

39. Technical Advisory Committee on Low-Level Radioactive Waste Management, Low-Level Radioactive Waste Management in North Carolina, Draft Report to the Governor's Task Force on Waste Management, September 30, 1980.

40. Washington State Department of Social and Health Services, Radioactive Materials License No. WN-I019-2, January 11, 1980.

41. Mullarkey, T. B., A Survey and Evaluation of Handling and Disposing of Solid Low-Level Nuclear Fuel Cycle Wastes, AIF/NESP-008, prepared by NUS Corporation for Atomic Industrial Forum, Inc., October 1976.

42. Colombo, P. and R. M., Neilson, Jr., Properties of Radioactive Wastes and Waste Containers. First Topical Report, NUREG/CR-0619, prepared by Brookhaven National Laboratory for U.S. NRC, August 1979.

43. Dow Chemical Company, The Dow System for Solidification of Low-Level Radioactive Waste from Nuclear Power Plants, Topical Report DNS-RSS-001-P, Prepared for U.S. NRC, March 1978.

44. Personal communication from Marty Carson, Chem-Nuclear Systems, Inc., to G. W. Roles, NRC, June 12, 1981.

45. Chem-Nuclear Systems, Inc., High Integrity Container Systems, November 1980.

46. Oztunali, O. I., et al., Data Base for Radioactive Waste Management, Volume 4: NUREG/CR-1759, being prepared by Dames & Moore for NRC, to be published.

47. U.S. Department of Energy, DOE Temporarily Stops Shipment of Its Low-Level Nuclear Waste to Commercial Burial Grounds, Press Release, October 26, 1979.

48. U.S. NRC, Final Programmatic Environmental Impact Statement Related to Decontamination and Disposal of Radioactive Waste Resulting from the March 28, 1979 Accident at the Three Mile Island Nuclear Station, Unit 2, NUREG-0683, March 1981.

49. U.S. NRC, Final Rule 10 CFR 72 Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation, Federal Register, 45 FR 74693, November 12, 1980.

50. U.S. Atomic Energy Commission, Draft Environmental Statement: Management of Commercial and Transuranium-Contaminated Radioactive Waste, WASH-1539, September 1974.

51. Martin, J. B., Director, Division of Waste Management, U.S. Nuclear Regulatory Commission letter to Sheldon Meyers, Program Director, Office of Nuclear Waste Management, DOE, December 5, 1979.

52. U.S. Department of Energy, U.S. Department of Energy Acceptance of Commercial Transuranic Waste, RFP-3110, February 1980.

53. U.S. Department of Energy, Managing Low-Level Radioactive Wastes: A Proposed Approach (A Program Document Prepared to Assist the U.S. Government in Formulating National Policy and to Solicit Public Comment and Discussion), prepared by the National Low-Level Waste Management Program, August 1980.

54. U.S. Department of Energy, Technology for Commercial Radioactive Waste Management, DOE/ET-0028, May 1979.

55. Blomeke, J. O., C. W. Kee, and J. P. Nichols, Projections of Radioactive Wastes to be Generated by the U.S. Nuclear Power Industry, ORNL/TM-5427, prepared by Oak Ridge National Laboratory for ERDA, December 1976.

56. Kee, C. W., A. G. Croff and J. O. Blomeke, Updated Projections of Radioactive Wastes to be Generated by the U.S. Nuclear Power Industry, ORNL/TM-5427, prepared by Oak Ridge National Laboratory for ERDA, December 1976.

57. U.S. Department of Energy, Western New York Nuclear Service Center Study. Companion Report, TID-28905-2, 1979.

58. Majumdar, D., and J P. Indusi, Draft Inventory of High-Level Nuclear Wastes in the United States, prepared by Brookhaven National Laboratory for NRC, draft completed March 1980.

59. Egar, K. J. and G. E. Zima, Commentary on Spent Fuel Storage at Morris Operation, NUREG/CR-0956, prepared by Pacific Northwest Laboratory for NRC, July 1979.

60. Oak, H. D., et al., Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, NUREG/CR-0672, prepared by Battelle Pacific Northwest Laboratory for NRC, June 1980.

61. Elder, H. K., and D. E. Blahnik, Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant, NUREG/CR-1266, prepared by Pacific Northwest Laboratory for NRC, October 1980.

62. Schneider, K. G., et al., Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278, prepared by Pacific Northwest Laboratory for NRC, October 1977.

62. Jenkins, C. E., E. S. Murphy, and K. J. Schneider, Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant, NUREG/CR-0129, prepared by Pacific Northwest Laboratory for NRC, February 1979.

Appendix E

DESCRIPTION OF A REFERENCE DISPOSAL FACILITY

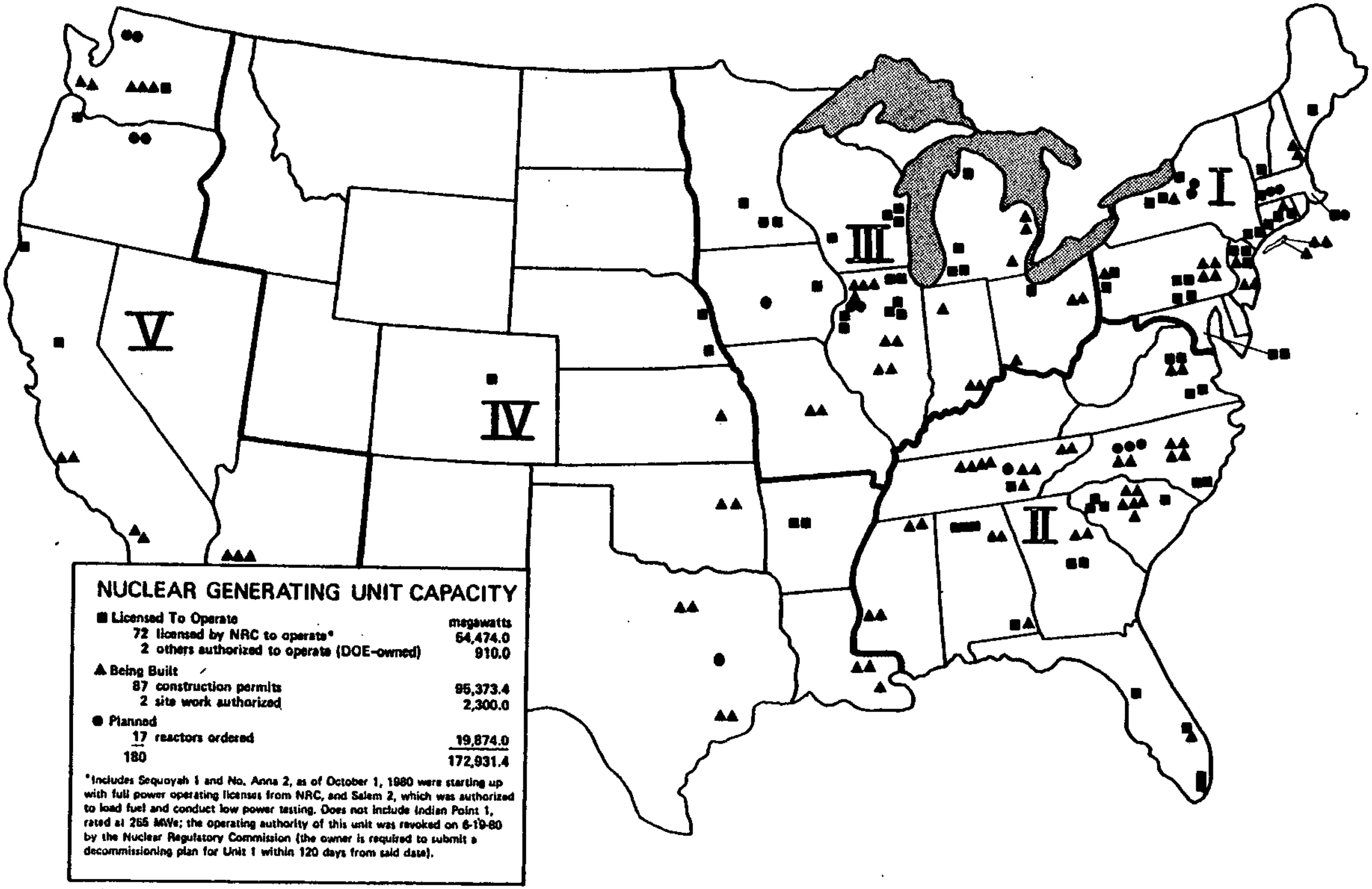
INTRODUCTION

This appendix provides a description of a reference near-surface disposal facility which is located in a humid environment in the eastern United States. The disposal facility is representative of existing disposal facility design and operating practices and is used to determine base case costs and impacts of waste disposal. The costs and impacts of alternative disposal facility designs and operating practices as well as alternative waste forms may be then assessed against those of the base case.

For purposes of this environmental impact statement, NRC staff has divided the continental United States into 4 regions corresponding to the states making up the U.S. NRC Regions. These regions are termed in this environmental impact statement: (1) the northeast region (NRC Region 1); (2) the southeast region (NRC Region 2); (3) the midwest region (NRC Region 3); and (4) the western region (NRC Regions 4 and 5). These regions are shown in Figure E.1. Within each region a hypothetical near-surface disposal facility site is assumed to be located having environmental characteristics typical of the region. The sites, however, are not intended to represent any particular locations within the regions. The specific environmental conditions described for each regional site do not correspond to any existing disposal facility site. In addition, the volumes of low-level waste (LLW) projected to be generated within each region over the next 20 years are estimated (see Appendix D), thus providing a source term for regional waste disposal.

However, the purpose of this environmental impact statement is to develop overall performance objectives and technical criteria for LLW disposal rather than performing a generic environmental assessment of regional disposal of LLW. To develop these overall performance objectives and technical criteria, a cost-benefit evaluation is made of alternative waste forms and disposal facility design and operating practices. To focus on this cost-benefit analysis in Chapters 4, 5, and 6 of this statement, NRC staff also developed a reference radioactive waste source term based upon an average of the volumes of waste projected to be generated in the four regions. This reference source term was then normalized to a total 20-year volume of one million m^3 of LLW, and is given in Appendix D.

This reference source term is then assumed to be disposed into a reference disposal facility which is conservatively assumed to be sited in a humid environment. NRC staff anticipates that over the next 20 years, over three-quarters of the waste generated in the United States will be generated in humid environments--i.e., in the eastern and humid midwestern sections of the country. Regional disposal of waste therefore implies that most of the waste generated in humid environments would also be disposed in humid environments.



BECAUSE OF SPACE LIMITATIONS, SYMBOLS DO NOT REFLECT PRECISE LOCATIONS

Figure E.1 U.S. NRC Regions

Potential ground-water impacts from existing or future disposal facilities are a strong function of actual site-specific meterological and geohydrological conditions, and would be analyzed by NRC on a case-by-case basis. However, potential ground-water impacts (and actions required to protect ground water) at a humid site are generally expected to be greater than those at an arid area. Some of the conditions at an eastern humid site which would indicate this include the relatively higher annual precipitation, shallower depth to ground water, and relatively shorter distances from the disposed waste to the point of ground-water discharge into surface streams.

Of the four hypothetical regional disposal facilities developed in this environmental impact statement (see Appendix J), three (northeast, southeast, and midwest) are located in humid environments. However, site-specific conditions such as amount of percolation, soil cation exchange capacity, speed of ground water, and population density vary somewhat from one site to the next. For this environmental impact statement, environmental conditions corresponding to the southeastern site were assumed, principally because of the rather high percolation assumed for this site in addition to the moderate permeability and ion-exchange capacity of the site soils. The staff believed that these conditions would enable a clearer comparison of the alternatives considered. Otherwise, there was really no compelling reason to choose one site over another. The site environmental conditions of the referenced (southeast) site are described in this appendix. The site environmental conditions of the other three sites are described in Appendix J.

The reference facility and site are used to analyze and to develop overall LLW disposal performance objectives and technical criteria in Chapters 4 through 6. Following this analysis, the unmitigated impacts of applying these performance objectives and technical criteria to the 4 regional disposal facilities are addressed in Chapter 10.

In developing the reference disposal facility, NRC staff was influenced by past history and experience at shallow land burial disposal facilities, and by the desire to emphasize potential long-term costs and radiological impacts in this environmental impact statement. For example, a great deal of experience has been gained over the years regarding handling and disposal of radioactive material. Safe working procedures have been recognized and developed such as the need to maintain strict control of potential site contamination to help minimize personnel exposures and potential offsite radioactivity releases during site operations. In addition, based on past experience with shallow land burial facilities as well as with nonradioactive solid and hazardous (chemical) waste disposal facilities, a number of criteria and recommendations regarding the siting of disposal facilities have been developed by the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), and others. Many if not most of these criteria and recommendations involve the application of common sense. An example of a good reference in this regard is the USGS Open-File Report No. 74-344 ("Storage of Low-level Radioactive Wastes in the Ground, Hydrogeologic and Hydrochemical Factors") prepared by USGS for EPA (Ref. 1).

NRC believes that the development of good siting criteria and good operational practices are important considerations in radioactive waste disposal. However, as stated above, the development of good siting criteria and operational radiation safety practices are to a large part an application of common sense. The main focus of this environmental impact statement, therefore, is the potential long-term costs and impacts of waste disposal--in particular, the potential long-term costs and radiological impacts associated with slumping, subsidence, and other potential site instability problems--as well as methods which can be used to mitigate these potential problems. NRC has previously stated that an overall objective for waste disposal is to close a disposal facility so that it is left in a condition such that the need for active ongoing maintenance is eliminated and only passive surveillance and monitoring are required at the point when the license is terminated (see Appendix I).

In this appendix, therefore, the reference disposal facility is developed assuming that an application for a new facility is received, and NRC's Low Level Waste Licensing Branch Technical Position on disposal facility closure and stabilization (Appendix I) is applied during the subsequent regulatory application review and licensing process. A number of common sense siting considerations and radiation safety practices are also assumed. However, given these siting considerations and radiation safety practices, no special effort is assumed to be made in the reference facility to ensure long-term site stability. This is used to provide a base case level of long-term costs and radiological impacts against which measures to achieve site stability, to minimize radiological impacts, and to ensure adequate funding can be assessed. Many of these measures (e.g., compaction of backfill material and trench caps, and disposal of more stable waste forms) are already being applied today. They have not been assumed for the base case facility, however, in order that the need to incorporate them into technical criteria can be analyzed as a part of this EIS.

The reference facility is sized to accept a relatively large quantity of waste--i.e., 50,000 m^3 of waste per year over a 20-year operating life, or a total volume of one million m^3. This corresponds to approximately one-quarter of the total volume of LLW projected to be generated in the United States to the year 2000. Disposal of a million m^3 of waste in the reference facility described in this appendix will require up to a few hundred acres of land, which corresponds to an approximate upper bound of the land area of current commercial disposal facilities.

The remainder of this appendix is divided into six sections which describe: (1) the lifespan of a reference facility, (2) basic considerations and assumptions regarding the siting of the facility, (3) the environmental characteristics of the disposal facility site, (4) the reference disposal facility design parameters, (5) the basic operational procedures utilized at the reference facility, and (6) the reference facility costs. A list of references is provided in Appendix E, Section 7.

1. REFERENCE FACILITY LIFESPAN

This section provides an overview of the assumed lifespan of the reference disposal facility described in this appendix, including siting, licensing, operation, and eventual closure of the facility. The lifespan is described based upon consideration of existing disposal facilities, existing NRC regulations and licensing procedures, and the existing Low Level Waste Licensing Branch Technical Position "Low Level Waste Burial Ground Site Closure and Stabilization" (see Appendix I). The lifespan can be conveniently separated into 5 phases as summarized in Figure E.2 and discussed in more detail below.

Figure E.2 Life Cycle of a Typical Near-Surface Disposal Facility

Number of Years	Activity	Description
1-2 years	Site Selection and Characterization	Site selection and characterization activities are carried out by the applicant in coordination with NRC, and state and local governments. A preferred site is selected and the site characterized in detail. A license application is prepared which includes a preliminary closure plan, environmental report, arrangement for government ownership of the land, lease arrangements for use of the site, and financial arrangements to cover the costs of closure and post-closure activities.
1-2 Years	Preoperational Licensing	The application is submitted to NRC (including a license fee) and docketed. A notice of receipt of the application is published in the Federal Register and an opportunity for requesting hearings is provided. State and local government officials are notified. An analysis of the application is carried out by the NRC licensing staff including preparation of an environmental impact statement. If no hearings are requested and upon a satisfactory licensing finding, NRC takes action to issue the license. A Notice of Issuance is published in the Federal Register and state and local government officials are notified. If hearings are requested, hearings are held including any Commission reviews and appeals. Upon resolution of all hearings and appeals and upon a satisfactory finding, NRC issues the license, notices issuance, and notifies officials.

Figure E.2 (Continued)

Number of Years	Activity	Description
20-40 Years	Construction and Active Disposal Operations	Upon issuance, the operator begins operations to construct the facility and to receive and dispose of waste. On a periodic basis, (about every 5 years, or as stated in the license), NRC reviews the licensee's program including the preliminary site closure plan, financial arrangements for closure and postclosure activities, and continued assessment of environmental impacts.
1-2 Years	Site Closure and Stabilization	During the operating phase, the site is generally stabilized (e.g., trench caps are put in place) as it is filled. At closure, final site stabilization activities are carried out. Facilities not needed for postclosure activities are decontaminated and dismantled. Costs for closure are provided by financial arrangements of the operator. Upon satisfactory closure, NRC terminates the license and control of the site revert back to the government landowner.
100 years	Institutional Control	The landowner carries out custodial care of the site which includes continued government ownership and control of the site and carrying out activities such as posting, maintaining site security, monitoring of the environment, and carrying out any maintenance activities such as correction of subsidence depressions in trench covers due to consolidation of the waste. The terms and conditions of the lease and financial arrangements of the operator and owner provides funds to cover the costs of these activities.

The 5 phases include: (1) site selection, (2) preoperational activities, (3) disposal operations, (4) site closure, and (5) an institutional control period. The overview is intended to provide a backdrop for the discussion in the subsequent sections regarding such activities as siting, designing, operating, and closing the disposal facility, as well as funding for closure and for institutional control. The overview helps to place the timing and extent of these activities into perspective.

As part of the discussion on the lifespan of the reference facility, reference is made to interactions between an applicant or licensee and a regulatory (licensing) agency. The applicant submits an application to a licensing agency which is then reviewed in accordance with licensing procedures established by the licensing agency. For the purposes of this appendix, the licensing agency is assumed to be NRC and the licensing procedures described are those of NRC.

1.1 Site Selection and Characterization Phase

Once the need and desire to operate a waste disposal facility has become established, the potential applicant embarks on a site selection study which is assumed to last approximately 1 to 2 years. The intent of the site selection study is to review and evaluate potential locations for a disposal site through a systematic process, and to gather sufficient data to support a license application. There are a number of methods or procedures by which the site selection study may be carried out. A brief outline of a method assumed to be used by the potential applicant is described below.

For the purposes of this appendix, the potential applicant is assumed to first establish a region of interest within which the potential applicant would propose locating a near-surface disposal facility. Depending upon the particular circumstances, this region of interest may be of a variable size--e.g., encompassing a single state or potentially a multiple-state region. From within this region of interest, the potential applicant selects a number of candidate areas within which perhaps 8 to 12 potential sites may be identified. This list of potential sites is then narrowed down to a slate of alternative candidate sites (3 to 5 sites) from which a most-favored site is eventually selected.

In arriving at a slate of candidate sites, the potential applicant principally uses reconnaissance level information in obtaining needed hydrologic, geologic, demographic and other data. That is, use is made of such information as relevant scientific literature (e.g., topographic, geologic, water resource, biotic, and demographic maps, as well as aerial photographs), reports of government or private research agencies, consultation with experts, and short-term field investigations, as well as analyses performed using such information. The amount of information collected and the extent of analyses conducted increases as the potential applicant moves from consideration of the region of interest to the slate of candidate sites. In analyzing the data, eliminating unfavorable areas, and eventually arriving at the slate of candidate sites, the potential applicant is assumed to use a number of common sense siting considerations such as avoiding heavily populated areas, fractured media, active faults, or floodplains. These and other basic siting considerations are discussed in more detail in Appendix E, Section 2. An additional consideration, which is assumed to be of importance to a potential applicant, is the availability of a good local road network. Socio-economic factors such as current land use and the availability of labor or local utility services are also important considerations to the potential applicant.

To assist in selecting a most-favored site from the slate of candidate sites, the potential applicant is assumed to drill a small number of subsurface reconnaissance wells at each of the slate of candidate sites. This is to help determine the agreement between the regional hydrologic data base and more specific site conditions. Several of these reconnaissance wells are later converted into monitoring wells at the candidate site eventually proposed in the application for license (see Appendix E, Section 1.2).

The potential applicant is now assumed to purchase the site (approximately 200 acres) most favored among the slate of candidate sites and to initiate the detailed subsurface investigation of the site. From this field investigation, the potential applicant is assumed to prepare such items as detailed boring logs, numerous cross-sections of the site geology, a site topographic map with a scale no greater than 1 inch = 100 ft, and a site potentiometric surface map for each aquifer of interest. In addition, the potential applicant is assumed to define the engineering and material properties of the soil units used for disposal, backfill, or trench caps, and to prepare a site drainage drawing.

It is assumed that a range of 25 to 50 wells of variable depths are drilled to determine the subsurface conditions of the site. Many of the peripherally located wells are assumed to be subsequently converted into ground-water monitoring wells. The potential applicant commences preoperational monitoring of the site, which helps to provide the data needed to support the license application as well as the baseline from which the effects of site construction and waste disposal are identified. The preoperational monitoring program includes periodic collection of surface water, ground water, biota, soil, and airborne particulate samples by an appropriate method (e.g., grab, continuous or composite sampling). Ground water levels and stream flows are measured periodically. Site meteorological data--particularly precipitation, wind speed and direction at various heights, temperatures, and soil moisture data--are also measured.

Throughout the site-selection phase, the potential applicant is assumed to have had a series of discussions with state representatives regarding custodianship of the disposal facility, and with funding mechanisms for long-term care of the facility.

During the final year of the site-selection phase, the investigations performed at the favored and candidate sites are assumed to have sufficiently and favorably progressed so that the potential applicant has reasonable confidence that there are no insurmountable technical or political problems. The potential applicant is then assumed to reach a management decision to proceed with the undertaking and preparation of a license application is initiated.

1.2 Preoperational Phase

This phase of the facility life span is assumed to last approximately two years and mainly consists of submittal of a license application to NRC and subsequent review by NRC licensing staff. During the review period, the applicant continues with the preoperational environmental monitoring program.

Upon receipt of the application, NRC would docket the application. If the application is incomplete, NRC would notify the applicant of the items needed to complete the application. In addition, upon docketing the application, NRC would notify the governor and the state legislature of the state in which the proposed site is located that a license application had been received. It is expected that this notification would be only a formality as considerable prior contact with state representatives by the applicant is highly probable.

The application would include a safety analysis part and an environmental report pursuant to 10 CFR Part 51. The environmental report would include a detailed description of the proposed action, a statement of its purposes, a description of the environment affected, and a description of the potential effects of the facility on that environment. As part of this, the proposed site (previously termed the most favored site among the slate of candidate sites) is described in detail. The potential environmental consequences and methods to mitigate these consequences are addressed, as well as alternatives to the proposed action, including alternative sites.

Also included with the license application is a preliminary site closure plan. This plan will include a detailed plan for waste emplacement, expected capacity of the site, the planned site contours and drainage systems during operations as well as the final site contours, and delineation of the buffer zone. The closure plan will include: (1) estimated costs of labor, equipment and material for closure and stabilization, and (2) long-term labor and material costs for eventual site surveillance, monitoring, and control by the site owner.

Once the complete application has been received and docketed by NRC, the receipt of the application is announced in the Federal Register in compliance with Part 2 of the Commission's regulations. A press release is also issued. In the Federal Register notice, opportunity is provided for persons with an interest in the proposed action to request a hearing. If such a hearing is to be held, NRC will appoint an Atomic Safety and Licensing Board (ASLB) to review the licensing action. Meanwhile, the application is reviewed by NRC licensing staff and a safety evaluation report is prepared. If the information contained in the application is insufficient to prepare the safety evaluation report and reach a decision, additional information may be requested from the applicant.

Under existing NRC regulations in 10 CFR 51, issuing a license for a waste disposal facility constitutes a major federal action according to the National Environmental Policy Act of 1969. Accordingly, an environmental impact statement (EIS) is prepared by the NRC staff and a draft published for public comment. Based upon public comment received and perhaps based upon additional information obtained from the applicant, a final EIS is prepared and published. Upon consideration of the final EIS, NRC staff will make decisions regarding the application and, if a license is granted by the Commission, any license conditions that the staff believe are necessary. If a hearing is held, NRC licensing staff would recommend a course of action (i.e., either rejecting the application, or granting a license subject to conditions) to the ASLB. Testimony would be presented and intervenors would be given an opportunity to cross-examine witnesses. The ASLB will review all testimony but ultimately would reach a decision on the application. This decision may be appealed to the Atomic Safety and Licensing Appeal Board, then to the Commission, and finally to the courts. Hearings, including preparation and presentation of testimony and preparation of the hearing record leading to a decision would last approximately one year.

After resolution of any hearings and appeals, the NRC staff may issue a license. Before the license can be issued, however, ownership of the disposal facility site must be transferred to either the state or federal government and an acceptable funding arrangement must be provided.

For purposes of this appendix, the facility site is assumed to be transferred by the applicant to the control of an agency of the state in which the site is located. The state is assumed to enter into a lease arrangement with the applicant. The terms and conditions of the lease are assumed to be reviewed on a 10-year basis, with the exception of funding arrangements, which are assumed to be reviewed on a 5-year basis.

Funding arrangements are established as part of the lease, and include specific arrangements to provide funds for: (1) disposal facility closure and stabilization; and (2) long-term site surveillance and control by the site owner (in this case the state). The availability of funding for facility closure and stabilization is assumed to be assured through a surety bond acquired by the applicant. This surety bond would be used by the state to close the site should the applicant default (e.g., go out of business). Otherwise, the applicant would pay for final site closure. (As discussed in Appendix K, in many cases existing disposal facilities did not provide for the specific availability of funds for site closure. Financial assurance, however, is part of the NRC Low Level Licensing Branch Technical Position on Site Closure and Stabilization and is presently being applied to operating sites.) Funding for long-term care and surveillance is assumed to be provided by a surcharge on waste received and disposed at the facility. Monies collected from this surcharge are placed into an interest-bearing state account which is dedicated to the long-term care of the facility. (Also see Appendix Q for a discussion of the funding assumptions used in the numerical analyses.)

1.3 Operational Phase

The licensee is now able to commence construction at the site. Construction at the site may be divided into two activities: facility construction, and operational construction and site utilization.

Facility construction is assumed to include erection of a security fence around the restricted area, a perimeter gravel road, and a number of support structures including an administration building, a warehouse, a garage, a health physics facility, and an initial waste disposal cell. It is expected that construction of the required facilities for the disposal site will consume a few months to a year. At the point when the licensee is ready for waste acceptance, NRC would inspect the site to ensure that the facility is constructed in accordance with the license. If NRC is satisfied that this is the case, the licensee would be allowed to begin to receive and dispose of waste. Operational construction continues through the operational phase of the site and includes such activities as trench excavation, waste emplacement, backfilling, construction of trench caps, and maintenance of site drainage patterns. Internal access roads would also be laid out as needed by the licensee.

During the operational phase, waste is received by the licensee, inspected for compliance with federal regulations and license conditions, and disposed. Groundskeeping, maintenance, environmental monitoring, recordkeeping and other support activities also are performed during this phase. A small security force is assumed to be present to help control access to the site. During this phase, funds are collected as part of a lease arrangement with the state as a surcharge on the waste received from customers. These funds are placed into state-controlled interest-bearing accounts for long-term site care.

The licensee's operations are periodically inspected by NRC inspectors for compliance with license conditions and NRC regulations. In addition, the licensee would periodically submit an application for license renewal, at which time additional site data gathered during facility operations, the licensee's operations, and the license conditions are formally reviewed by NRC licensing staff. NRC anticipates that these license renewal activities would normally occur at approximately 5-year intervals. With each license renewal application, the licensee provides an updated site closure plan with special attention paid to potential revisions in long-term funding arrangements.

Approximately one year before the site is filled to capacity, the licensee submits a final site closure plan for review by NRC. This final closure plan would include a description of final estimates of costs, environmental impacts, data needs, material and equipment needs, planned documentation and quality assurance, as well as a detailed plan of trench locations and elevations in expected capacities, planned surface contours, and buffer zones. The final plan would also include a schedule for implementation of any remaining uncompleted plan elements, and a description of the mechanics of orderly transfer of control of the site to the site owner.

1.4 Site Closure Phase

Upon review and acceptance of the site closure plan by NRC, the site closure plan is implemented by the licensee. Final site closure, including any remaining site stabilization and contouring, will be carried out during this period. The type of activities in this phase may also include decontamination of facilities, equipment, and land, as well as decommissioning of buildings (dismantlement of the majority of structures). Surveys of the site are carried out to ascertain the acceptability of the site surface with respect to surface contamination for the institutional control period. It is expected the closure phase will last one to two years. The funding for site closure activities is assumed to come from either the licensee or from the surety funds provided for as part of the closure plan.

1.5 Institutional Control Period

After the site has been closed, the disposal license is assumed to be terminated and the responsibility for the site passed to the site owner. This phase is termed the institutional control period and may be divided into two periods: the active institutional control period and the passive institutional control period. At the beginning of the active institutional control period, the license is terminated and control over the site is transferred back to the owner (in this case, the state government). The active institutional control period is anticipated to last up to one hundred years while the passive institutional control period has an indefinite duration. During the active institutional control period, the site owner would be engaged in the normal activities of land ownership including routine inspections, fence maintenance, trench cap repairs, vegetation control, and monitoring activities. Funds for these activites are provided by the monies collected as a surcharge on received wastes and placed into an interest-bearing state account dedicated for this purpose. Cost estimates for these activites are provided in Appendix E, Section 6. During the passive institutional control period, the site owner is assumed to hold the title and do little or no site inspection or maintenance.

2. BASIC SITING CONSIDERATIONS

Radioactive wastes have been buried in near-surface disposal facilities since World War II. Between World War II and 1962, the United States Government was the principal entity involved in near-surface disposal of radioactive waste. Since 1962, six commercial disposal sites have been licensed and have operated within the United States. The federal and commercial disposal facilities have provided over 35 years of experience. Based upon observed performance of these facilities, specific recommendations made by federal regulatory agencies and panels of experts, and existing regulations promulgated for environmental protection, some basic siting considerations become apparent.

Among the important federal agencies and groups which have addressed basic radioactive waste disposal facility siting considerations are the U.S. Geological Survey, U.S. Environmental Protection Agency, and the National Research Council (Refs. 1-4). Basic low-level radioactive waste disposal facility design considerations have also been addressed by NRC (Refs. 5-6). Siting requirements developed by EPA for nonradioactive solid and hazardous waste disposal may also be considered (Refs. 7-10), as well as criteria on flood plain management and protection of wetlands (Refs. 11-14). Siting criteria for radioactive and nonradioactive solid and hazardous waste disposal have also been developed by the states (Refs. 15-16). Siting criteria recently promulgated by NRC for disposal of uranium mill tailings may also be considered (Ref. 17).

2.1 Hydrologic Considerations

Based on past experiences at disposal sites, the observed underlying causes for some difficulties experienced, and recommendations made by organizations such as those described above, there appears to be at least six basic hydrologic factors which should be considered during site selection. These six hydrologic factors are:

1. The subsurface media in which disposal is made should be relatively homogeneous and lacking elements of lithological complexity or highly unpredictable geometries.

2. The waste disposal cells should be located above the highest seasonal water table.

3. The surface of the disposal site should be devoid of significant surface water features such as swampy conditions, large scale hydrologic depressions which do not allow rapid drainage, wetlands, and ponds.

4. The site should not be located in a floodplain. Investigations should be able to demonstrate that no waste disposal will occur within a 100-year floodplain.

5. Sites should be located outside of coastal hazard areas.

6. Sites should have long ground-water travel times between disposal cells and potable drinking water supplies or ground-water discharge areas. Ground-water travel times in excess of the period of radiological hazard are obviously preferrable; however, shorter ground-water travel times may be acceptable given suitable hold-up by waste form and packaging, by engineering barriers, and/or by site characteristics such as extremely low ground-water flux or high sorption.

Simple subsurface media is preferred for disposal sites so that reliable transport predictions can be made and a representative monitoring network established. Should a source term (i.e., trench leachate) become available for transport at a disposal site, a reliable prediction can provide a description of the probable levels of contamination potentially released offsite. These predictions of radionuclide transport can be checked against monitoring data throughout the operational period.

Should calculations and measurements indicate the potential for significant releases (i.e., in excess of applicable standards), remedial measures could be performed to mitigate the potential effects of offsite subsurface contaminant migration. Conversely, at a site where the substrate was characterized by extreme heterogeneity (e.g., multiple discontinuous layering of materials with highly variable permeabilities), prediction monitoring and remedial control of contaminant transport may be difficult.

As long as the waste is kept above the highest generally observed water table, the probability of significant contact time between waste and ground water can be kept low by engineering design and construction. The greater the volume of water in contact with disposed waste, the longer the time of contact and the greater the extent of leaching of radiocontaminants that can be expected. This is clearly an undesirable situation.

Avoiding significant surface water features such as wetlands, swamps, bogs, and other stagnant water conditions serves three major purposes: (1) protection of important wildlife habitats, (2) protection against intrusion of significant quantities of water into the disposal cells, and (3) avoidance of short ground-water travel times to drinking wells or discharge areas.

The federal government has provided direction with respect to avoidance of flood plains (Refs. 8, 10 and 11). Among the obvious reasons for avoiding siting within a floodplain are the probability of floods and erosion. It is clearly not advisable to construct a disposal facility in a floodplain where floodwaters could potentially inundate the site and carry waste packages away. Additionally, an area susceptible to flooding generally implies a relatively high susceptibility for large-scale erosion which can compromise the integrity of the disposal cells. Avoiding coastal high hazard areas is also intended to prevent significant flooding or erosion of the disposal site.

Finally, a long ground-water travel distance between disposal cells and the nearest receptor point or discharge area is desired so that radioactive decay, dispersion, and/or retardation can reduce potential impacts resulting from potential offsite contamination. For example, it may not be desirable to locate a new disposal facility within close proximity (e.g., 500 meters) of a municipal drinking water well field. Similarly, given the desire for a long ground-water travel time, it may not be advisable to locate a site within close proximity to a perennial surface stream.

2.2 Geologic Considerations

In many ways, geologic siting considerations overlap many of the hydrological considerations. However, these considerations are not necessarily directly related to water and its contact with waste. Among the basic "common sense" considerations with respect to site geology are:

1. Disposal within horizons containing highly fractured, jointed, or cavernous media should be avoided.

2. Disposal at sites with significant topographic relief which may result in slope failures, extreme erosion rates, etc., should be avoided.

3. Disposal in areas where active fault zones have been identified should be avoided.

The rationale is straightforward. Disposal within horizons containing highly fractured media introduces substrate complexity and an enhanced secondary permeability. Substrate complexity results in reduced ability to reliably predict, monitor or mitigate contaminant transport. This results in decreased ability to mathematically model the site and to perform environmental monitoring with some appreciable level of confidence. Highly fractured media also enhances unpredictable contaminant transport.

The rationale behind avoiding significant topographic relief relates to the desire to avoid slope instability, and to the ability to manage surface water, prevent erosion, and construct disposal cells having reliable performance. With respect to surface water management, a slight to moderate slope aids in the runoff of surface water and minimizes infiltration into the disposal cells. However, if the slope is too steep, then the higher velocities associated with runoff water may produce accelerated erosion or may necessitate surface runoff control systems that require active maintenance. In addition, local floodings could be a problem during periods of high flow. Construction and management of acceptable disposal cells can also be difficult on steep slopes.

Although ground acceleration from earthquakes should not normally adversely impact a disposal site, seismic activity can pose problems under certain circumstances. At a typical near-surface disposal facility consisting of burial trenches, three seismic concerns can potentially impact the performance of the site. The three major seismic concerns are liquefaction, structural damage, and horizontal/vertical displacement.

Liquefaction appears to be of concern only if wastes in the disposal cells in the unsaturated zone move downward into liquefying deposits below the disposal cells. Potential structural damage at a "burial trench" facility could occur to the supporting structures during site operations. However, potential environmental releases would be expected to be minimal as all or nearly all of the radioactive material at the facility would be in a solid form. If engineered structures are employed as disposal cells, and the integrity of these disposal cells is considered the major barrier against long-term release of radionuclides, then these structures may have to be designed to withstand the expected maximum ground motion for the particular region. The third concern for "burial trench" facilities is anticipated to result from horizontal or vertical fault displacements on the scale of feet or tens of feet which could expose waste or otherwise compromise the integrity of the trench caps. This type of occurrence is expected to occur only in the vicinity of an active fault zone, which should be identifiable and avoided during site selection.

2.3 Demographic and Nonradiological Environmental Considerations

Principal demographic and nonradiological siting considerations include the following:

1. Areas of high population density should be avoided.

2. Areas which have high recreational potential should be avoided.

3. Historic areas or areas which constitute habitats of unique or endangered flora or fauna should be avoided.

4. Areas with a potential for significant economic development of natural resources should be avoided.

Areas of high population density should be avoided to minimize the potential for intentional or unintentional intrusion and reduce potential impacts from waste disposal. Areas containing scenic vistas or recreational lands such as lakes, national parks, and forest preserves should be avoided in compliance with existing federal laws and regulations. In addition, the disposal facility should not be located where nearby facilities or activities could adversely impact the long-term performance capability of the site.

3. DISPOSAL SITE ENVIRONMENT

In this section, the environment of the reference disposal facility site is described. The description is meant to be representative of the southeastern United States but should not be construed to represent any existing site or any particular location, or NRC advocacy of any particular site or location. The site environment includes information on meteorology, hydrology, topography, soils, geology, seismicity, ground water, surface water, background radiation, demography, and resources. The section is divided into five subsections: meteorology, hydrogeology, demography, ecology and natural resources.

3.1 Meteorology

The reference disposal facility is assumed to be located within a humid subtropical climatic regime. The annual average precipitation at the site over the past twenty years has been 1168 mm (46 in), with an annual range of 838 to 1473 mm (33 to 58 in). Four distinct seasons are observed at the site, although the winters are somewhat short and mild with an average temperature of 9°C (48°F). The summers within the region of the site are characterized by warm weather with temperatures generally averaging between 24° and 27°C (75° and 81°F). The temperature characteristics of the site are given in Figure E.3.

The relatively mild temperature variation observed at the site suggests that large-scale desiccation and frost-heaving of trench caps are not likely to occur. The highest intensity storms result from the remnants of inland travel of hurricanes and tropical storms. The maximum 24-hour rainfall recorded at the site over the last twenty years is 152 mm (6 in). Snowfall at the site is generally light and rarely exceeds three inches for one snowfall. The average snowfall is 12 mm (0.5 in). Snowfall is generally observed during the months of January and February. Precipitation event intervals for the reference disposal site are shown in Figure E.4.

A water balance calculation for the site is presented in Table E.1. This calculation has been described by others (Ref. 18) and is used to determine monthly quantities of precipitation, evapotransportation, run-off and infiltration (percolation) at the reference disposal site. As shown in the table, approximately 180 mm (7 in) out of an annual 1168 mm of precipitation percolates into the site soils.

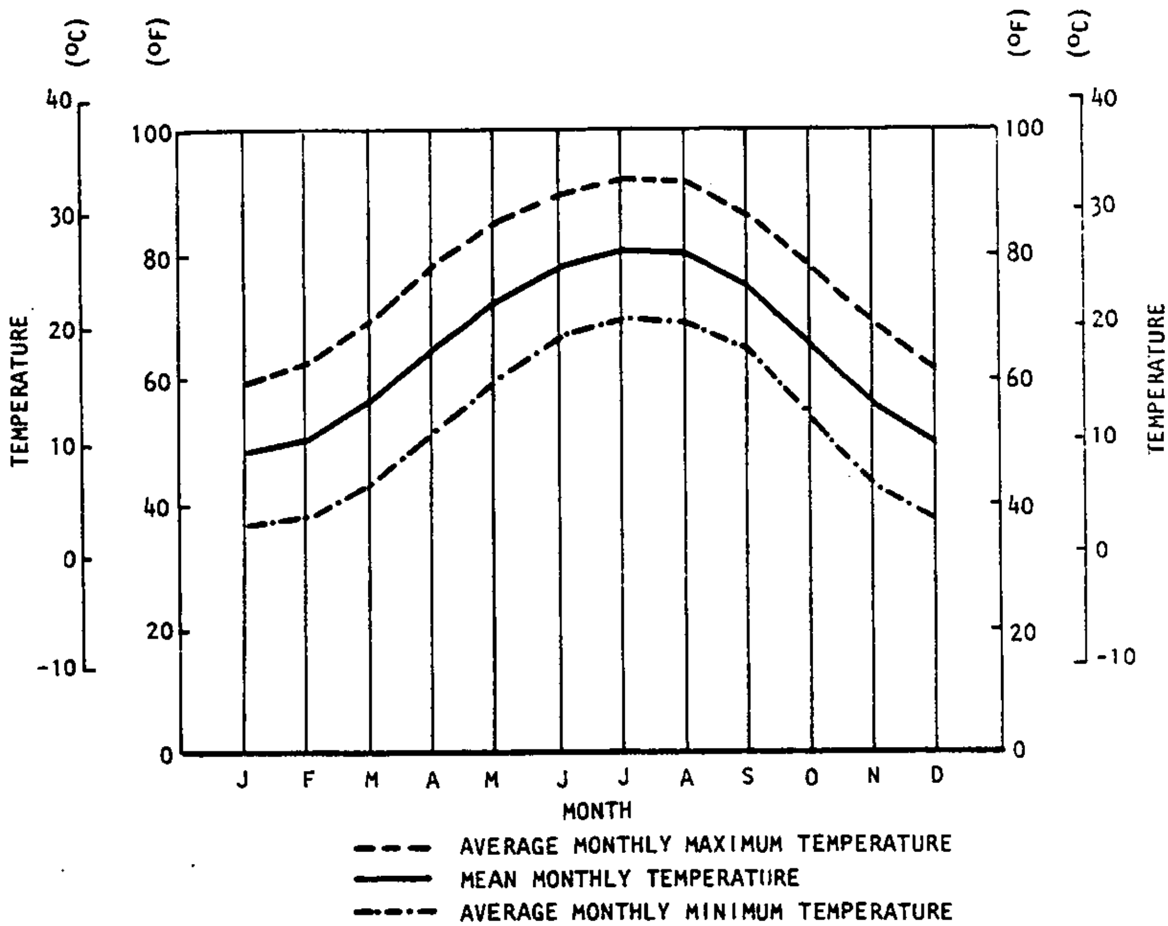


Figure E.3 Mean Monthly Temperature - Reference Disposal Facility

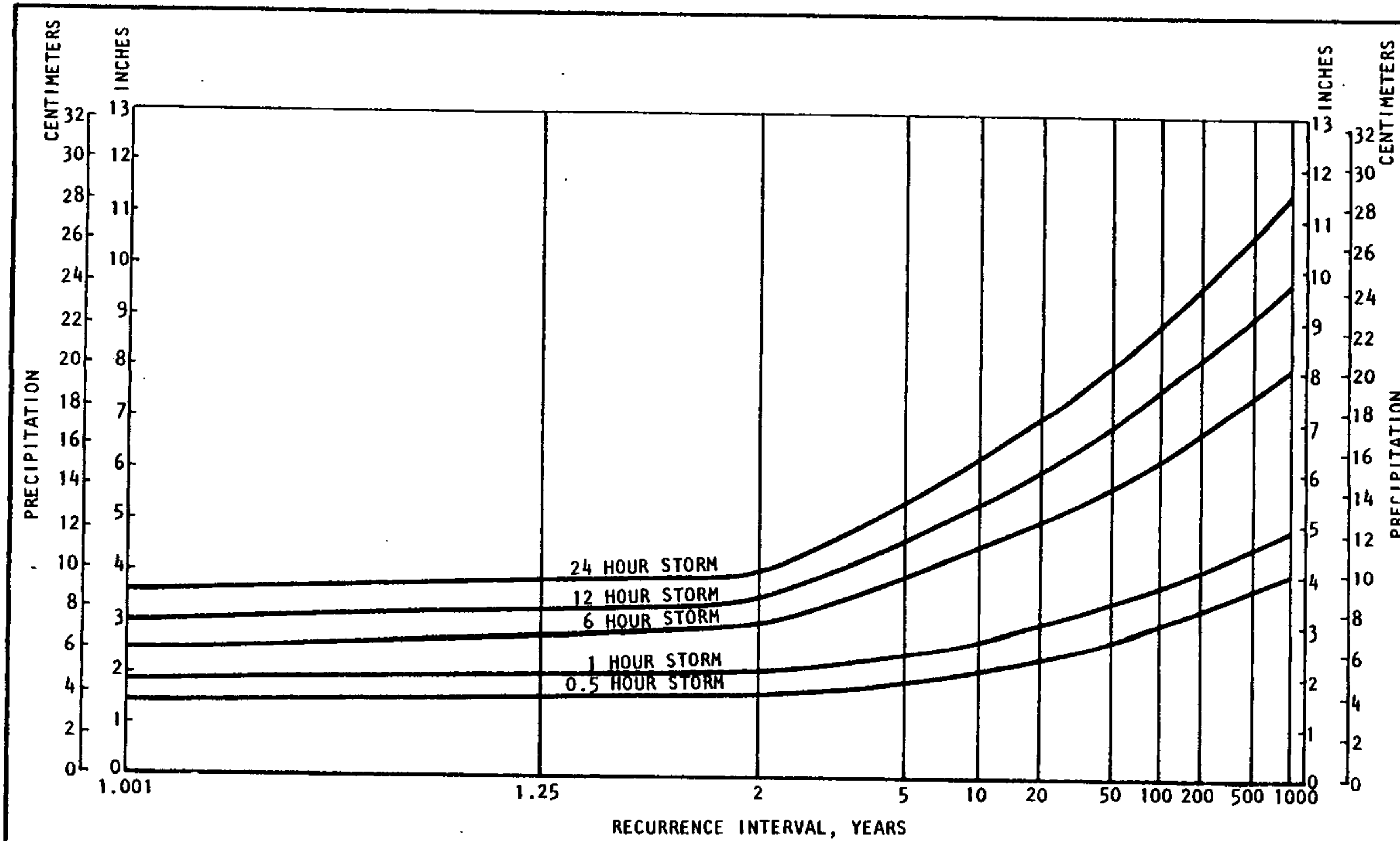


Figure E.4 Precipitation Event Recurrence Intervals - Reference Disposal Facility

Table E.1 Water Balance Calculation for Reference Disposal Facility

	J	F	M	A	M	J	J	A	S	O	N	D	Annua
PET	13	15	37	65	115	158	172	157	114	64	29	13	952
P	80	100	96	84	82	102	149	147	103	64	77	81	1168
C	.14	.14	.14	.14	.14	.12	.12	.12	.12	.12	.14	.14	
R	11	14	13	12	11	12	18	18	12	8	11	11	151
I	69	86	83	72	71	90	131	129	91	56	66	70	1014
I-PET	56	71	46	7	-44	-68	-41	-28	-23	-8	37	57	62
CNS					-44	-112	-153	-181	-204	-212			
S	100	100	100	100	64	32	21	16	12	11	48	100	
ds	0	0	0	0	-36	-32	-11	-5	-4	-1	37	52	
AET	13	15	37	65	113	147	162	151	107	63	29	13	915
PERC	56	71	46	7	0	0	0	0	0	0	0	0	180

S_M = Maximum soil moisture storage (mm)
P = Precipitation (mm)
C = Surface runoff coefficient (dimensionless)
R = Surface runoff (mm)
I = Infiltration (mm)
PET = Potential evapotranspiration (mm)
I-PET = Difference between (I) and (PET) (mm)
CNS = Cumulative sum of negative (I-PET) (mm)
S = Soil moisture storage (mm)
dS = Change in soil moisture storage (mm)
AET = Actual evapotranspiration (mm)
PERC = Percolation into ground-water system (mm)

The prevailing winds at the site are south-southwesterly with an average wind speed of 13 km/hr (8.8 mph). The wind rose for the site is presented in Figure E.5. The average humidity at the site is 78%, with an average low of 68% usually occurring in January and an average high of 88% occurring in August.

Tornado activity within the immediate area of the site proper is moderate with an estimated occurrence of one tornado every 500 years. Within 50 km (31 mi) of the site, the occurrence frequency of tornadoes is on the order of once every fifty years.

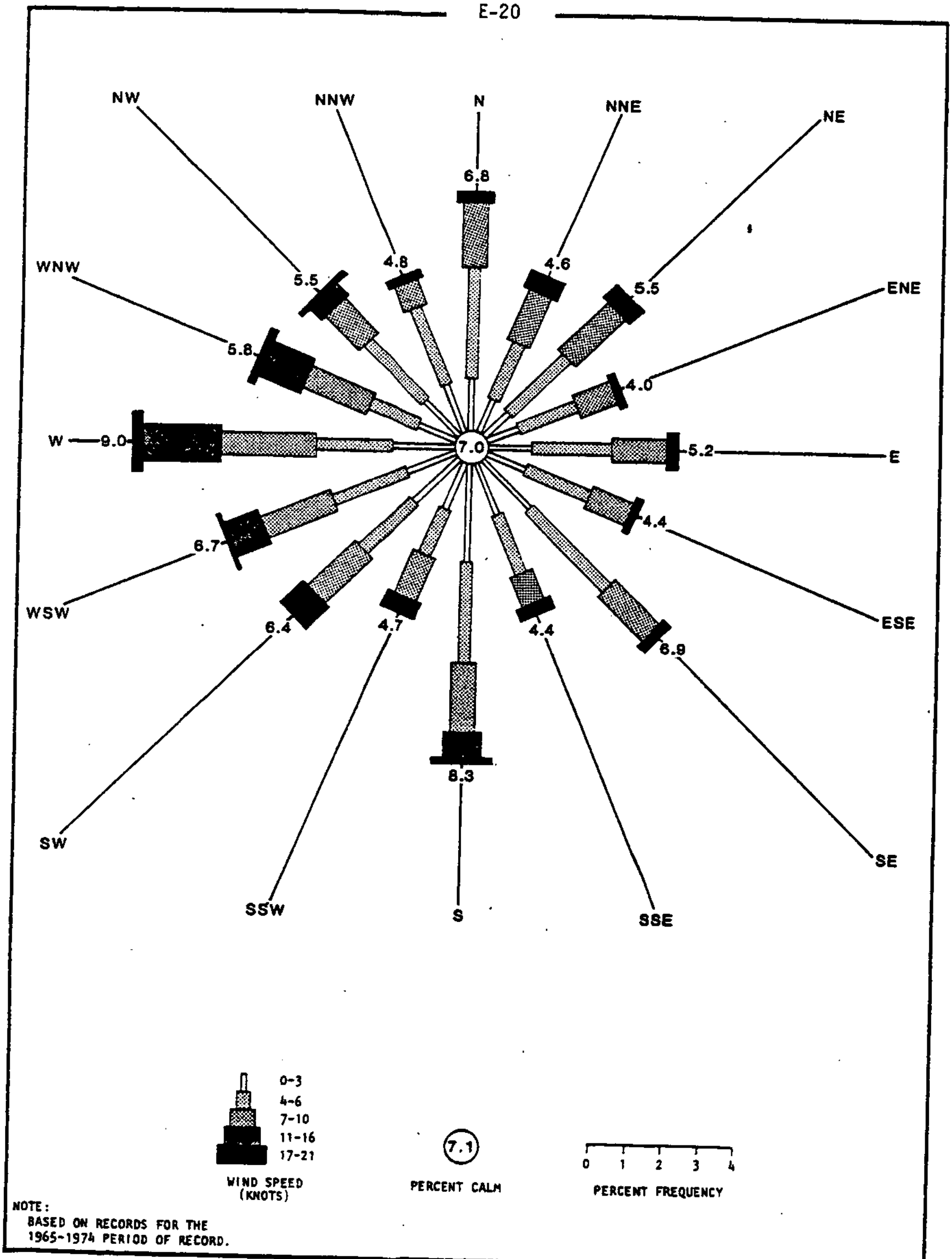


Figure E.5 Wind Rose Diagram - Reference Disposal Facility

The air quality at the site is quite good with concentrations of all major pollutants below USEPA standards (see Table E.2). The good air quality is largely due to a lack of point sources of pollution near the site. The only major point source of airborne pollutants is a coal-fired electrical generating station located 43 km (27 mi) to the northeast of the site. Farming activity on land adjacent to the site is also a source of air pollutants.

Table E.2 Air Quality at the Reference Disposal Facility

Pollutant	Concentration (mg/m^3)	USEPA Standard
Suspended particulates		
24-hr average	90	150
annual average	45	60
SO_2 (annual average)	20	60
NO_X (annual average	28	100
Hydrocarbons		
3-hr average	70	160
annual average	68	-

3.2 Hydrogeology

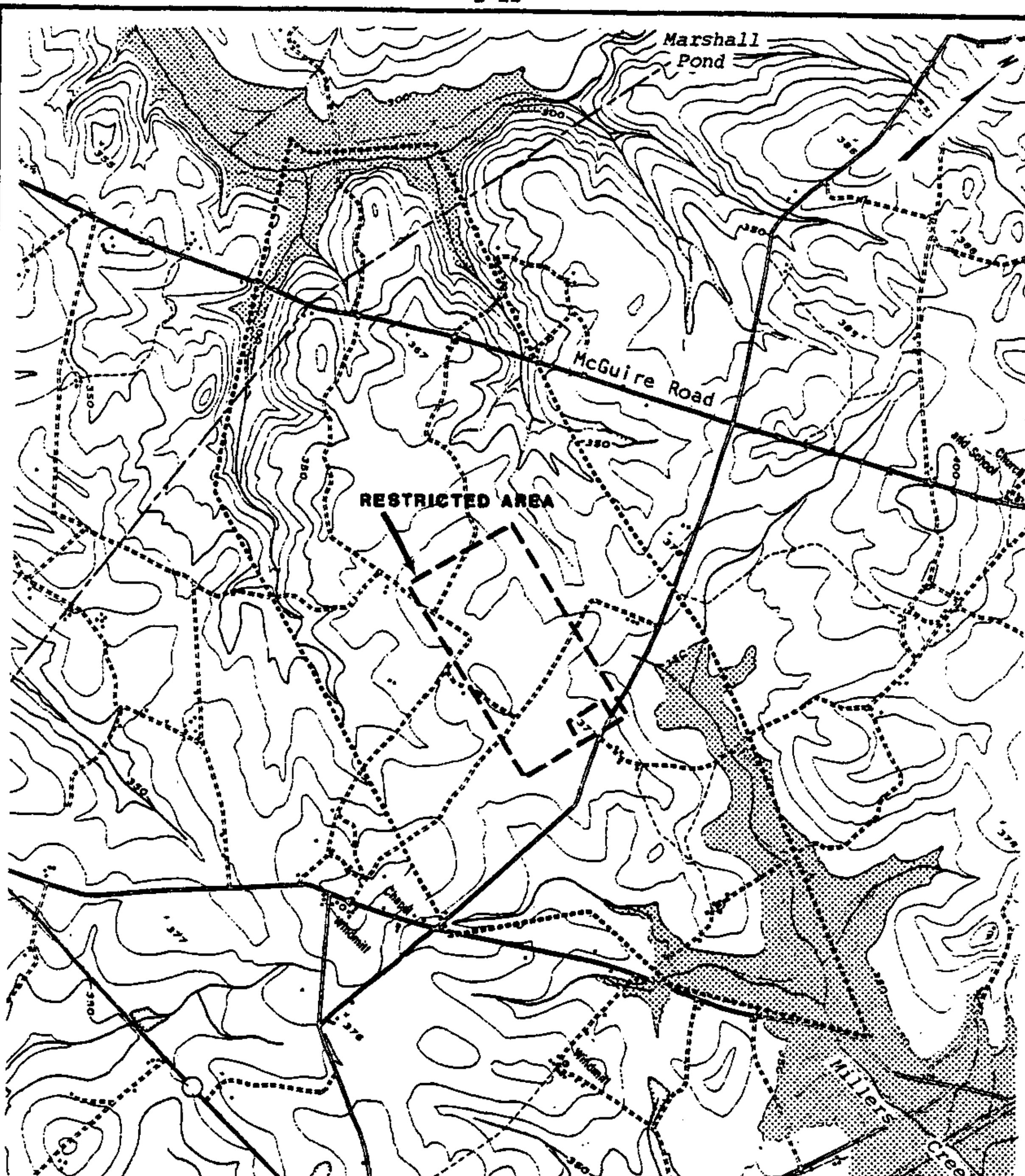
The elements of site hydrogeology discussed in this section include topography, geology, soils, seismicity, background radiation, ground water and surface water.

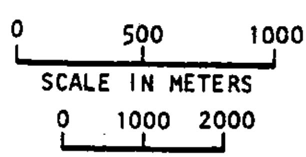
3.2.1 Topography

The site is located within the Liptone Upland segment of the Coastal Plain physiographic province at elevations ranging from 120 to 122 m (394 to 400 ft) above mean sea level (msl) (Figure E.6). The site vicinity is characterized by gently rolling hills with broad summits and by relatively flat-lying fields bordered by somewhat broad drainage depressions. In general, natural surface drainage at the site is good. As a result of the low topographic relief at the site, the probability of mass wasting and other significant erosional events is low. The local drainage system is dendritic with a typical perennial stream spacing of 1,000 to 2,000 m or more (3,280 to 6,560 ft).

3.2.2 Soils

The soils covering the reference disposal facility site are predominantly sandy loam and loamy sand. In engineering terms, these soils may be described as medium-dense silty sands and clayey sands. The surficial soils generally consist of 0 to 8 cm (0 to 20 in) of topsoil mixed with silty sand.





KEY:

500 YEAR FLOODWAY

Figure E.6 Topographic Map - Reference Disposal Facility

This surficial soil layer is underlain by 10 to 12 m of sandy clay sand from the Schwinn formation (Figure E.7). This sandy clay layer has an average permeability of about 5×10^{-6} cm/sec. Underlying this layer of sandy clay are unconsolidated and semiconsolidated sediments of the Eocene age Stablehead Formation. This sedimentary layer generally consists of fine-to-coarse sands which are locally partially cemented with occasional thin lenses of silt present. This sandy layer from the Stablehead Formation is approximately 12 to 14 m (39 to 46 ft) thick. The average permeability of this horizon is 1×10^{-4} cm/sec.

3.2.3 Geology

The geologic profile of the site is provided in Figure E.7. The site is underlain by 22 to 24 m of colluvium (see previous discussion for soils description). Underlying the colluvium is a cherty limestone (Winston Road) member of the lower Stablehead Formation. The limestone has an average permeability of approximately 10^{-2} cm/sec and forms the basal portion of the unconfined aquifer. Solution features in the limestone are minor and are not of the type which would result in sinkhole development. Underlying the Stablehead are Semour and Wrigley Clay members of the Brittle Limb Formation. The Seymour member is typically a well-bedded, fine to coarse grained, calcareous sand with clay lithofacies occurring as beds or lenses. The upper most portion of the Seymour in the site area consists of several thin limestone layers underlain by a clay layer. The Wrigley member consists chiefly of a calcareous, marine clay. The total thickness of the Brittle Limb Formation in the site area is about 45 meters. The clayey basal member of the Brittle Limb Formation serves as an aquiclude to deeper aquifers.

3.2.4 Seismicity

The reference disposal facility site is located within an area having a peak estimated horizontal ground acceleration of 0.11 G with a recurrence interval of more than 500 years. Capable faults have not been identified in the general vicinity of the site. The probability of significant ground displacement at the site is quite low.

3.2.5 Ground Water

The depth to ground water from the original ground surface at the site ranges from 12 to 17 m (40 to 55 ft). The aquifer is unconfined and is generally a subdued replica of the local topography. Well yields in the unconfined aquifer are typically in the range of 1-10 gpm. Larger capacity uses are satisfied by deeper wells into the confined aquifer. The ground-water quality is fair (it meets the National Primary Drinking Water Standards); however, the local consumptive use of water for potable purposes is low and consists of 6 domestic wells within 5 km (3.2 mi) and 60 wells used for farming and livestock. The closest down gradient well is located 1.4 miles from the site. Recharge to the local ground-water system primarily results from infiltration of precipitation. The closest major withdrawal location is 36 km (22.5 mi) to the northeast where water is pumped from the lower confined aquifer for a municipal drinking water supply.

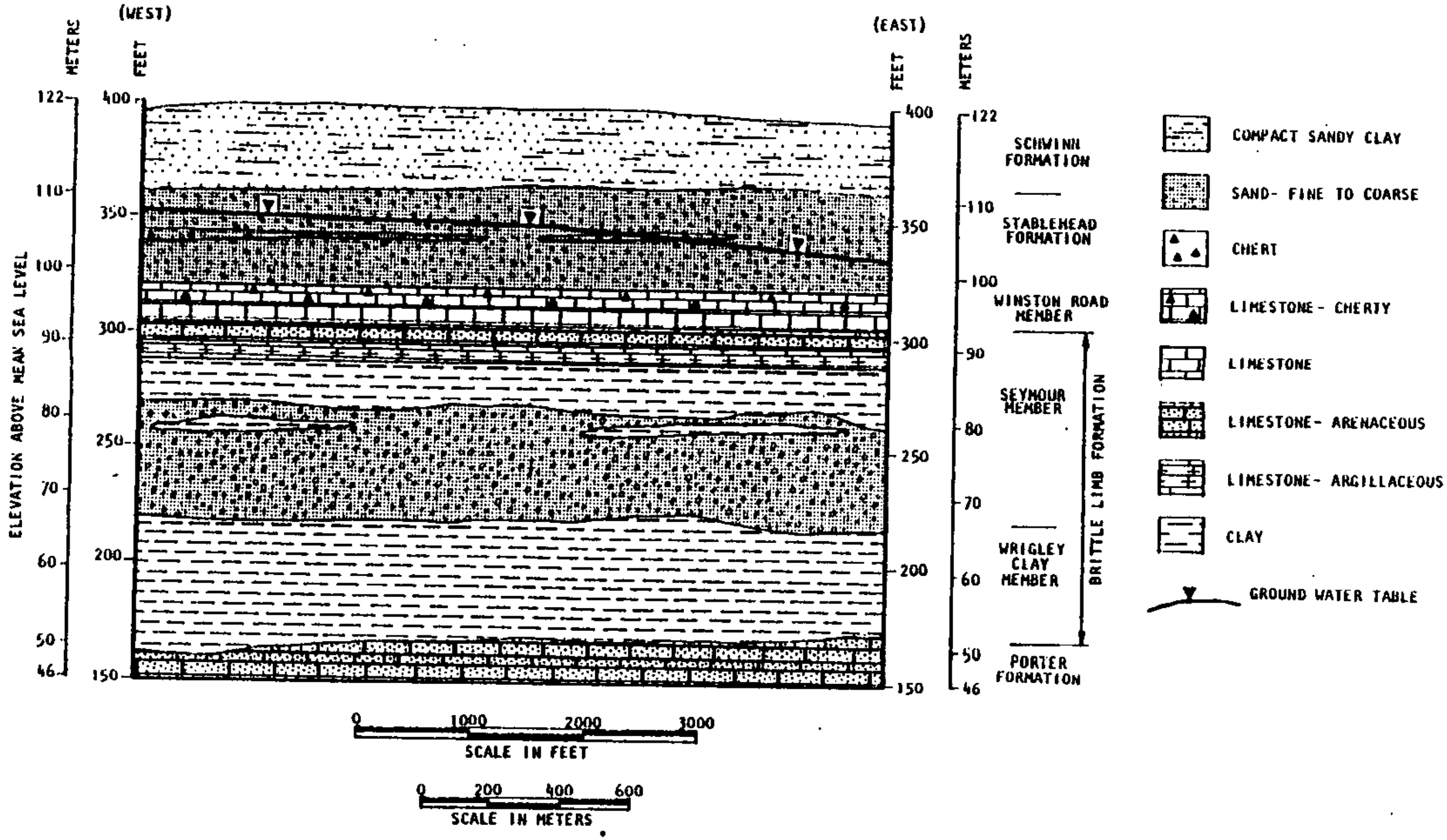


Figure E.7 Geologic Profile - Reference Disposal Facility

3.2.6 Surface Water

The nearest perennial stream to the site is Millers Creek which is located approximately 1000 m (3300 ft) to the southeast of the site (Figure E.6). This is the nearest point of ground-water discharge, at an approximate elevation of 295 ft msl. The other major stream in close proximity to the site is the Signal Branch of Basie Creek which is located approximately 2000 m (6600 ft) north of the site. Millers Creek discharges into the Bigard River which subsequently drains into the Parker River which ultimately empties into the Atlantic Ocean by way of Feather Bay. The Signal Branch has an average discharge of 0.028 m^3/s (1 ft^3/s); this stream drains into the Basie Creek and the Turner River, which eventually drains into the Pepper River and ultimately into the Atlantic Ocean.

3.2.7 Background Radiation

Background radiation at the disposal site is composed of terrestrial radiation and cosmic radiation. Terrestrial radiation at the site is a direct function of the geology of the site area, while cosmic radiation is a direct function of the topographic elevation and geographical location of the site (e.g., latitude and longitude). Background gamma radiation at the site is estimated to be about 10 uR/hr with about half of the radiation from terrestrial sources and half from cosmic sources. Background levels of radiation in surface water and ground water are quite similar with an average preoperational tritium concentration of 350 pCi/l, a gross alpha concentration of 4 pCi/l, and a gross beta concentration of 12 pCi/l.

3.3 Demography

The site is located in a rural area which is characterized by agricultural land, forests, some small industrial development, and some small residential communities. The population distribution within an 80.5 km (50 mi) radius of the site is shown in Table E.3. The total population within 8 km (5 mi) of the site is only 1,685, with a density of 8.6 people/km^2 (21.5 people/mi^2). Approximately 50 km to the northeast of the site is the city of Hawkinsville with a population of 175,000 (see Figure E.8); a cluster of smaller suburban communities surround Hawkinsville. There are five small rural communities (each with a community population of less than 2,000) within 20 km (12.5 mi) of the site. Within 2 km (1.25 mi) of the site are approximately 45 residences, two churches, one schoolhouse, and two windmills.

The economic base of the area is primarily agricultural. The total labor force within 48 km (30 miles) of the site is estimated to be 75,000 full time workers. Of that total, 50% of the work force is devoted to manufacturing (predominantly electronics, textile, and light equipment), 35% to farming (cotton, soybeans), 5% in retail sales labor, 5% in construction, and 5% employed by public utilities.

Table E.3 Population Distribution of the Reference Disposal Facility

Radial Distance from Site Miles	Existing-1980 Population Number	Existing-1980 Average Density per mi² (per km²)	Existing-1980 Cumulative Population	Projected-2010 Population Number	Projected-2010 Cumulative Population
0-5	1,685	21.5 (8.6)^{P}	1,685	2,024	2,024
6-10	6,602	28.0 (10.8)	8,287	8,115	10,139
11-20	26,667	28.3 (10.9)	34,954	36,000	46,149
21-30	117,920	75.1 (29.0)	152,874	124,995	171,134
31-40	191,200	87.3 (33.7)	344,794	203,435	374,569
41-50	90,460	18.0 (7.0)	435,254	104,933	479,502

3.4 Ecology

3.4.1 Terrestrial Ecology

Much of the general area of the reference disposal facility is composed of undeveloped woodland, which is dominated by long leaf pine (Pinus palustris) and turkey oak (Quercus laevis). The herbaceous layer is mostly turkey oak saplings, but bluejack (Q. marilandian), post oak (Q stellata) and long leaf pine are also important. In addition to the pine-upland hardwoods found near the disposal facility, two other forest communities are found: bottomland hardwoods along Signal Branch and bluff hardwoods along the steeper slopes of Millers Creek. Water oak, black gum and tupelo gum (Nyssa aquatical) are the dominant overstory species in the bottomlands. Moist ground conditions result in substantial understory and ground cover. The bluff hard woods are characterized by hickory (Carya) and northern red oak (Quercus borealis). Understory speicies include water oak, northern red oak, ash (Fraxinus), and mulberry (Morus rudea).

Nestronia (Nestronia umbellula), a deciduous shrub that is considered to be threatened in the state, is expected to occur in the pine-upland hardwoods. It also may be found in the transition zone between these woods and the

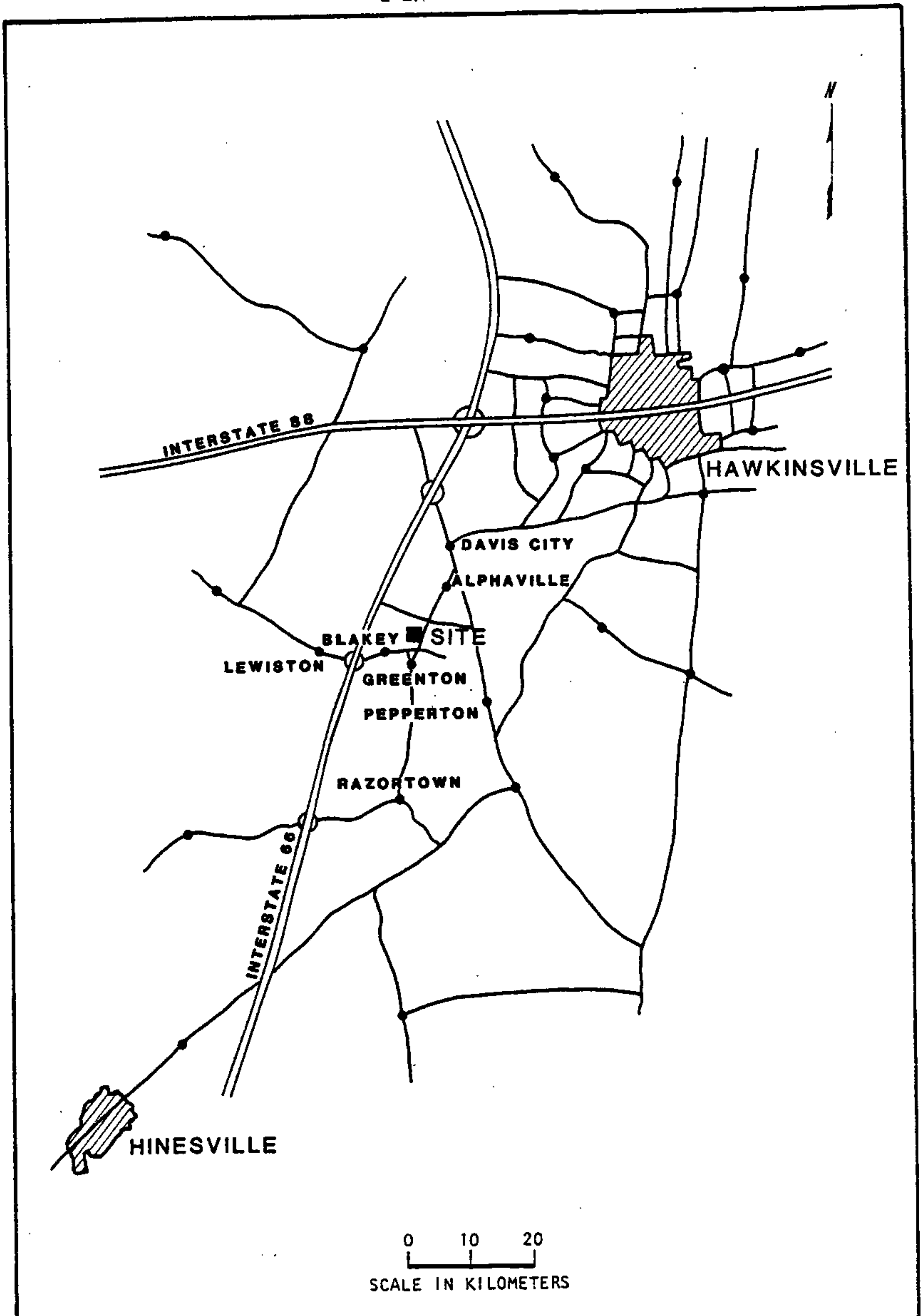


Figure E.8 Site Vicinity Map

bottomlands found closer to Signal Branch. While the bald eagle (Haliacetus leucocephalus) and red-cockaded woodpecker (Picoides borealis) may also be found in the county in which the site is located, they are not expected onsite or within 5 km of the site due to lack of suitable habitat. No other federally or state protected species are anticipated to inhabit the area.

The most common mammals found in the pine communities are the pine mouse (Pitymys pinetorum), fox squirrel (Sciurus niger), and raccoon (Procyon lotor). Burrowing species that have been observed are the southeastern pocket gopher (Geomys pinetis) and eastern mole (Rattus rattus). Gopher tunnels are generally over 100 feet in length and dug at a depth of 6 to 8 inches. While tunnels leading to the resting chambers of the eastern mole may be 6 inches deep, most are only 1 to 2 inches deep, and may extend for over a half mile.

Other mammals associated with the hardwood communities include the raccoon, opossum, woodrat (Neotoma floridana), flying squirrel (Glaucomys volans), gray squirrel, and swamp rabbit (Sylviagus aquaticus). Bobcat (Lynx rufus) and gray fox (Urocyon cineroargenteus) have also been observed. Common mammals found in the old field communities, and also in the cultivated fields are several species of mice (Reixthrodontomys and Peromyscus), cottontail rabbit, least shrew (Cryptotis parva), striped skunk, raccoon and opossum. Most mammals found in this area are not underground burrowers.

As with mammals, the different vegetative communities provide habitat for several varieties of birds. Common species of the pine communities include the slate-colored junco (Junco hyemalis), brown-headed nuthatch (Sitta pusilla), pine warbler (Dendroica pinus), bluejay (Cyanocitta cristata), and common crow (Crovus brachyrhynchos. The golden-crowned knight (Regulus satrapa), common flicker (Colaptes auratus), and pileated woodpecker (Hylatomus pileatus) are common in the hardwood forests. Predatory birds such as the red-shouldered hawk (Buteo lineatus), red-tailed hawk, Coopers hawk (Accipiter cooperii), and barred owl are also found in moderate numbers in these latter woodlands. These birds feed on rodents and other terrestrial vertebrates found in the area. The open fields and edge communities provide habitat for the eastern meadowlark (Sturnella magna), field sparrow (Spizella pusilla), mockingbird (Mimus polyglottos), robin (Turdis migratorius), and common grackle (Cassidix mexicanus). Dominant raptors in these areas are the marsh hawk (Circus cyaneus) and sparrow hawk (Falco sparverius). The fields also provide hunting areas for the other hawks mentioned.

The pine upland forests provide habitat for many snakes, including the corn snake (Elaphe guttata), northern pine snake (Pituophis melanoleucus), black racer (Coluber constrictor), and diamondback rattlesnake (Crotalus adamanteus). The burrow of a gopher tortoise (Gopherus polyphemus) has been also observed near the northwestern boundary of the site. The gopher tortoise is an accomplished burrower; its tunnels may be as wide as 12 inches, and generally as long as 35 feet. Many other animals temporarily or permanently use these burrows, including numerous insects, opossum, and diamondback rattlesnakes. The more common reptiles of moister hardwood communities are the dusky salamander (Desmognaturs), cricket frog (Acris gryllus), brown snake (Natrix taxispilota), and eastern box turtle. Active farming limits the diversity and abundance of the resident herptiles in cultivated areas. Species that were commonly found in the old field communities that may wander into cultivated fields include the southern toad (Bufo terrestris), six line racerunner (Cnemidophorus sexlineatus) and eastern hognose snake (Heterodon playrhinos). This latter species is known to burrow in search of food.

In general (with the exception of the upland pine areas) the biomass of southeastern forests and fields is high, compared to many other regions in the United States. Mild climate and sufficient rainfall promotes rich, stratified vegetative growth, which provides suitable habitat and abundant food source for many herbivores and omnivores. Primary and upper level carnivores, in turn, rely on the abundance of these species.

3.4.2 Aquatic Ecology

Primary producers of the two nearby creeks (Millers Creek and Signal Branch) include booth algae and macrophytes (aquatic vascular plants). Periphyton (attached algae) are more common in the flowing waters of these streams; however, increased turbidity or organic loading can quickly reduce the abundance and types of algae found.

Eight genera of aquatic plants were identified within the nearby creek water These plants are most abundant in areas of reduced current flow. The plants found, in descending order of abundance, are:

Common Name	Scientific Name	Relative Abundance
Water milfoil	Myriophyllum sp.	Most abundant
Hornwort	Ceratophyllum sp.	Most abundant
Alligator weed	Alternanters sp.	Very abundant
Water weed	Anacharis sp.	Abundant
Duck potato	Sagittaria sp.	Not abundant
Pickerel weed	Pontederia sp.	Scarce
Cattail	Typha sp.	Scarce

No endangered or threatened plant species are expected to occur. A significant diversity of invertebrate species are also found in these waters. The three most abundant groups, comprising just over 5 percent of the total number of insects sampled, are mayflies (Ephemeroptera), beetles (Coleopter), and waterfleas (Cladocera).

Approximately 38 species of fish are known to occur in the surface water system. The most abundant fish are shiners (Notropis sp), minnows (Cyprinidae sp.), sunfish (Centrarchidae sp.), and darter (Etheostoma sp). Common recreational species include largemouth bass (Micropterus salmoides), pickerel (Esox sp.), channel catfish (Ictalurus punctuatus), black crappie (Poxomis nigromaculatus) and sunfish. Two nearby ponds are more popular fishing areas, however, than Millers Creek and Signal Branch. Although several anadromous species do spawn in the rivers, no major spawning activity is noted in the above creeks. No protected fish species have been recorded for these waters.

3.5 Natural Resources

The principal nonagricultural natural resources within the vicinity of the site are minerals and land.

3.5.1 Minerals

The predominant mineral resources within 50 km of the site are dimension stone, crushed stone, sand and gravel, and clay. Development of extensive mining efforts for metals has not been made in the area of the site. There are no known precious metals or fossil fuel mineral deposits within 8 km of the site. Withdrawing the surficial sandy layers at the site for industrial use is not cost-effective due to their poor construction quality. Sand is mined at a local borrow pit. This borrow pit produces an average of 680 metric tons (750 short tons) annually. A kaolin (clay) borrow pit is operated approximately 16 km (10 mi) to the southwest of the site. There is little potential at the site for cost-effective withdrawal of kaolin for construction-grade clay, although limited quantities are available for onsite use. The principal dimension stone mined in the state is limestone. However, the small thickness and poor quality of the limestone formation beneath the site makes it generally unattractive to major dimension stone producers.

3.5.2 Land

Within an 81 km (50 mi) radius of the site, there are three principal categories of land use: (1) woodland, (2) farmland, and (3) developed land. Approximately 25% of the land area is woodland (both private and government preserves), 55% is farmland (with an approximate 50:50 mixture of row crops and pasture), and 20% is developed land (light industry and residential dwellings). The area occupied by the site had been used for farming in the past. However, for the last several years the land has been lying uncultivated and a thick secondary growth has grown up.

4. REFERENCE FACILITY DESCRIPTION

The description of the reference disposal facility is divided into two sections: (1) the basic site design, and (2) the support facilities and structures.

4.1 Basic Design

To provide a base case against which alternatives can be analyzed in this environmental impact statement, the disposal facility is assumed to have a total capacity of up to one million m^3 (35.3 million ft) of waste which is delivered to the disposal site at an annual average rate of 50,000 m^3 (1.77 million ft^3) and randomly disposed into shallow land burial trenches having a design which is typical of current practices. This results in a base case amount of land which is committed for waste disposal. Alternatives considered in this environmental impact statement for waste form and disposal facility design and operation will vary the amount of land committed for waste disposal. For example, increased processing and volume reduction of waste decreases the amount of land needed for waste disposal, while the alternatives considered in this environmental impact statement for facility design and operation may, depending upon the specific alternative considered, either increase or decrease the amount of land committed.

To develop the disposal facility, the licensee is assumed to purchase a plot of land covering 81 ha (200 acres), of which 60 ha (148 acres) is turned over to state ownership. This 60 ha of land is then leased back to the licensee and is used by the licensee for the reference disposal facility. The remaining 21 ha (52 acres) is retained by the licensee for possible future use.

A conceptual layout of the reference disposal facility is illustrated in Figures E.9 and E.10. As shown in the figures, the disposal facility may be divided into two basic areas: a "restricted area" and an "administration area". Pursuant to Part 20 of the Commission's regulations, the restricted area is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. The restricted area includes a "disposal area", in which disposal of radioactive waste takes place, as well as an "operational area". As shown, the restricted area includes a buffer zone between the disposal trenches and the restricted area fence of 30 m (100 ft). As shown in Figure E.9, the operational area is located along the eastern side of the disposal facility and is used as a borrow area for cask storage and for other miscellaneous functions. The operational area includes two facilities, a decontamination facility and a garage, which are used to support waste disposal operations. The administration area is located near the eastern corner of the disposal facility and is considered uncontrolled by the licensee for purposes of radiation protection. The adminstration area includes support facilities plus parking space for employees as well as for incoming waste delivery vehicles. A more detailed discussion regarding the functions of the support facilities and structures is provided in Appendix E, Section 4.2.

The reference facility occupies a total of 60 ha (148 acres), including the disposal area, operational area, and administration area. As is the case at existing disposal facilities, however, considerably less than the total site acreage is used for waste disposal. For example, specific areas of a particular disposal site may not be suitable for waste disposal due to geohydrological or topographical reasons--e.g., parts of a particular site might have excessively steep slopes or high water tables. The administration area occupies 3.7 ha (9.1 acres), and is assumed to be a constant for all waste form and facility design and operation alternatives considered in this environmental impact statement. The area of the land committed for waste disposal--that is, the land actually containing disposed radioactive waste--varies according to the alternatives considered, but covers 35 ha (87 acres) at the reference facility. This area was calculated assuming random disposal (50% utilization of disposal space) of one million m^3 of waste into trenches having average dimensions of 180 m long by 30 m wide by 8 m deep, and having an average spacing of 3 m between each trench. The committed land use rate--that is, the unit volume of waste disposed per unit area of land--is estimated to be 2.88 m^3/m^2 (9.45 ft^3/ft^2). The remaining 21.3 ha (53 acres) includes the operational area and the 30 m buffer zone as well as any excess land within the disposal area used for roads, working areas, and so forth.

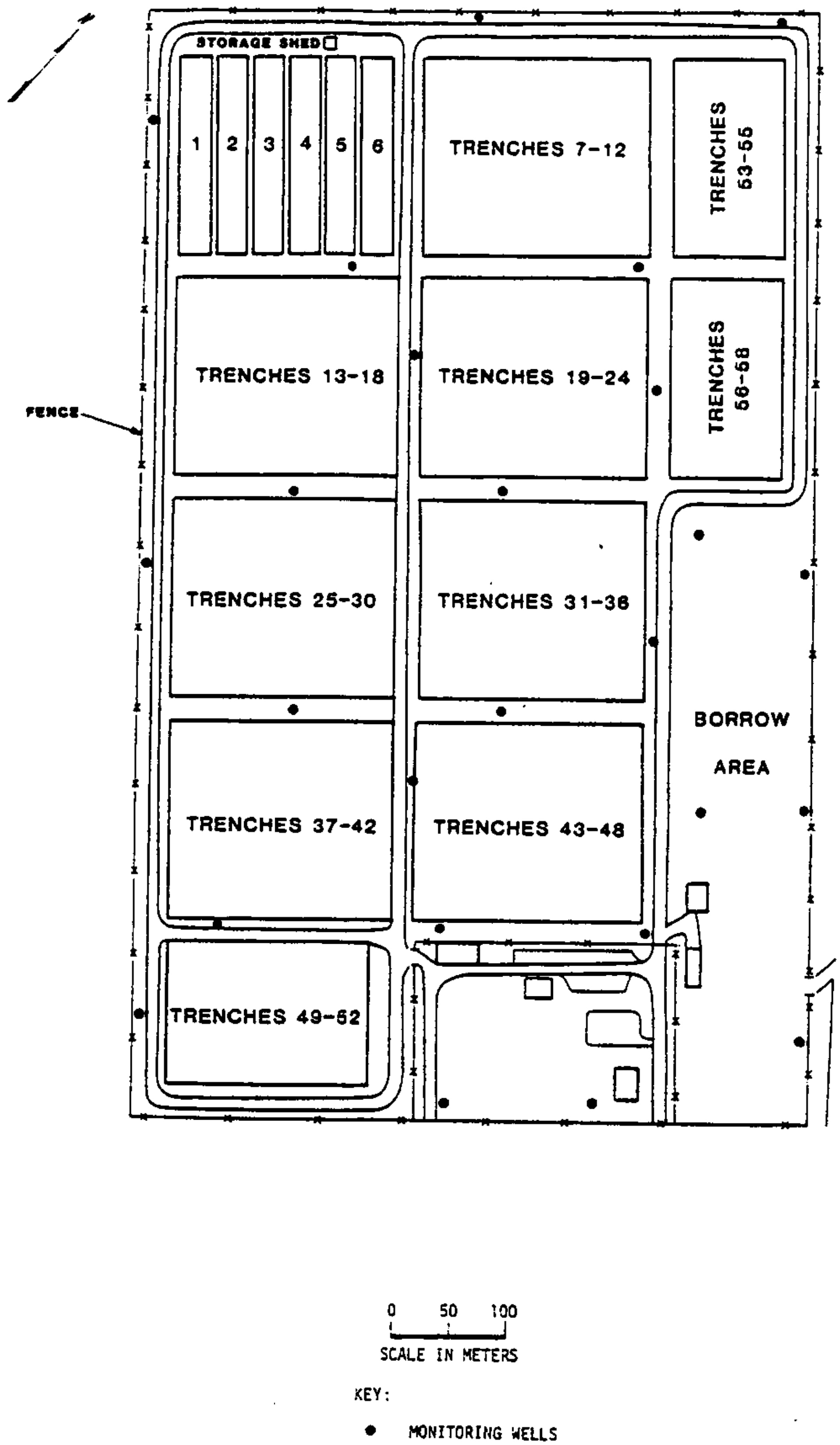


Figure E.9 Reference Disposal Facility Layout

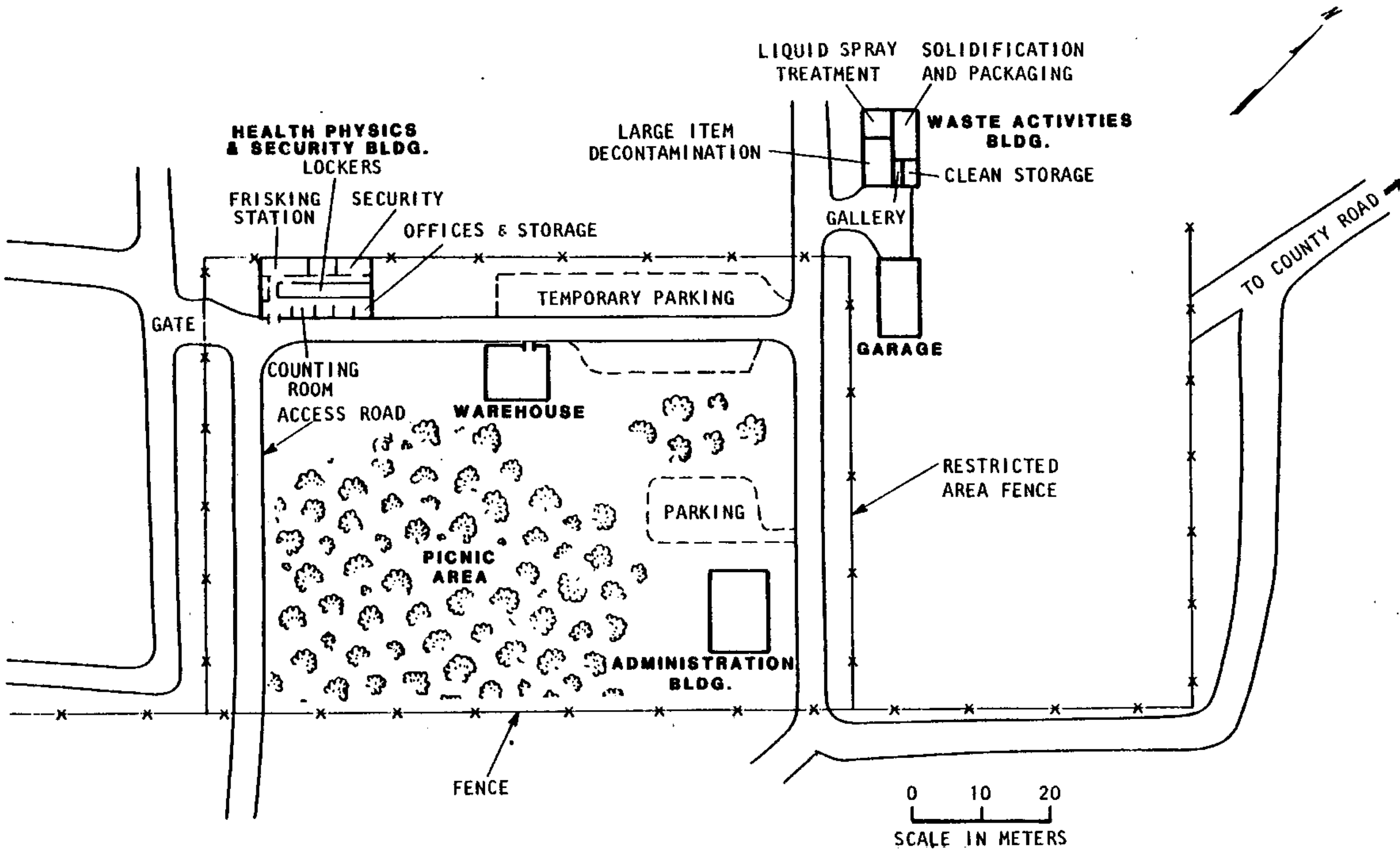


Figure E.10 Reference Disposal Facility Support Facilities

The entire site is surrounded by a 2.4 m (8 ft) high chain-link fence topped with three strands of barbed wire. A 2.4 m high fence also separates the administration area from the restricted area. Access to the disposal site is via a state highway running close to the site from which two short gravel roads lead onto the disposal facility. There are no rail facilities at the site. Incoming waste delivery and employee vehicles enter the site through one of two gates located in the administration area. These gates are locked at night and at other times such as holidays when the site is not being operated. Access to the restricted area is controlled by security check points near the gates in the fence separating the administration area and the restricted area.

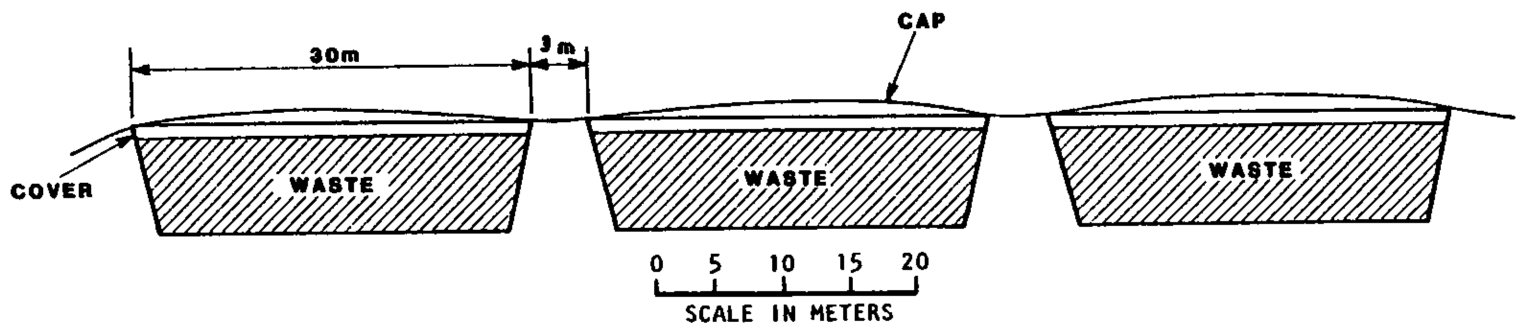
For security purposes, a narrow gravel road runs alongside the inside of the fence surrounding the restricted area. Other onsite gravel roads wide enough to accommodate two small vehicles lead to the active disposal areas and are constructed by the licensee as needed. A lighting system is provided in the operational and administration area. There are no other lights installed in the interior of the restricted area.

The disposal area at the reference facility includes 58 disposal trenches. The average disposal trench is assumed in this appendix to be 180 m (591 ft) long, 30 m (100 ft) wide, and 8 m (26 ft) deep (Figure E.11). However the length and width of the disposal trenches may vary somewhat (about ± 10 m). The rather large trench sizes assumed in this appendix are representative of recent trends at existing disposal sites.

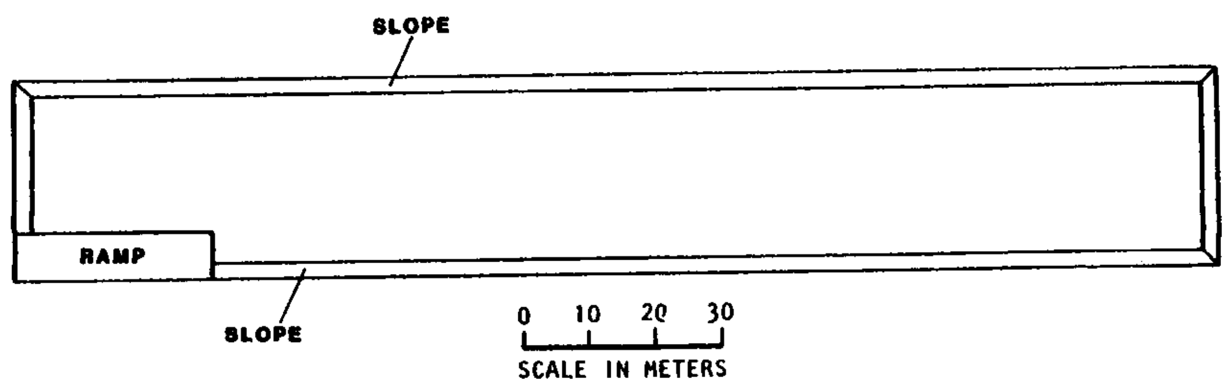
The site soils are cohesive, but not cohesive enough to allow vertical-walled excavations. Therefore, trench wall slopes of 1 horizontal to 4 vertical (1:4) are employed. In some circumstances, (e.g., when extensve sloughing occurs) more gentle slopes are employed. The trenches are separated by 3 m thick walls. These inter-trench walls are able to support only light vehicles. Other vehicles, including heavy construction and transport vehicles, require a more substantial substrate.

As a trench is constructed, the locations of the four corners of the trench are surveyed and referenced to a bench mark. An approximate one degree slope is provided in the bottom of a trench from end to end and from one side toward a 0.6 m x 0.6 m (2 ft x 2 ft) gravel-filled French drain. The French drain runs the entire length on the lower elevation side to provide for collection of any liquid drainage that might occur. A gravel-filled sump is located at the low corner of the trench.

Each trench is equipped with a minimum of three 0.15 m (6 in) diameter polyvinyl chloride (pvc) standpipes located within the French drain and standing along the sidewalls of the trench. The bottom three feet of each standpipe is fitted with either a slotted pvc pipe screen or a wound mesh pvc screen. Two of the three standpipes are located at each end of the excavation. The third standpipe is usually located at the trench midpoint (also standing in the French drain). These pvc standpipes function as observation wells or sumps.



TYPICAL TRENCH CROSS-SECTION



PLAN VIEW OF TYPICAL TRENCH

Figure E.11 Typical Trench Details

4.2 Support Facilities and Structures

The support facilities include: (1) an administration building, (2) a health physics/security building, (3) a warehouse, (4) a garage, (5) a waste activities building, and (6) a storage shed. All structures at the site are one-story metallic structures on concrete pad foundations. The building areas for these five major structures are listed below:

Building or Facility	Area m^2	Area ft^2
Administration	625	6,725
Health Physics/Security	800	8,610
Warehouse	470	5,060
Garage Mechanics	420	4,520
Waste Activities	560	6,025
Storage Shed	80	860

The functions of each of the support facilities are described below.

4.2.1 Administration

The administration building contains office space for site management and other administrative personnel working at the site. The activities performed within this building include coordination of waste shipments to the site, billing customers, and other routine file work. Site records are also stored within this building.

4.2.2 Health Physics/Security

The health physics/security building serves as the focal point for the majority of disposal activities at the site. This building houses a security section, a counting room, health physics offices, a change room/locker room, a lunch area, and a supply room. The health physics and security personnel are housed in the same facility because many of the functions performed by these personnel are complimentary. Security personnel check both site personnel and visitors into and out of the site through a centrally-located checkpoint. The health physics personnel have the prime responsibility for checking vehicles into and out of the disposal area. All persons leaving the site must pass through a frisker station to check for contamination which may have been picked up onsite. A safety decontamination shower is located adjacent to the frisker location. Emergency equipment such as safety ladders, respiratory equipment, and anti-contamination suits are stored in the vicinity of the frisker station. The employee change/locker room down the hall from the health physics offices includes both a street clothes ("clean") and work clothes area. Showers are also located in this section of the building.

4.2.3 Warehouse

The warehouse is used to store supplies used onsite. This facility is located within the administration area so that delivery trucks need not enter the disposal area. Among the stored items in this warehouse are cables, hooks, drums, bags, and other miscellaneous hardware. Casks and site vehicles are stored in the operational area.

4.2.4 Garage

Only vehicles and equipment that have been surveyed and decontaminated to within specified limits (see Appendix E, Section 5.2.5) are allowed to use the garage. The garage is large enough to hold two vehicles at a time for maintenance. Mechanic's tools, spare parts, oil, and fuel (adjacent to the building in underground tanks) are also stored in the garage.

4.2.5 Waste Activities

This building houses several functional areas, including: (1) a large item decontamination bay, (2) a control room for the decontamination bay, (3) a liquid treatment system, (4) a waste solidification, packaging, and overpacking area, (5) a supply room, and (6) a small waste storage area.

The decontamination bay is used for washing down (decontaminating) large pieces of equipment (including trucks if necessary) through the use of a high-pressure recirculating water supply system. Contamination levels in these decontamination liquids are generally quite low; however, water treatment is applied to recirculating fluids. Small-scale decontamination of tools and other small items may be accomplished within the solidification staging area. The solidification area includes batch concrete mixing equipment for solidification of small quantities of low-activity liquids. A small storage area is provided for occasional temporary storage of shipments received from common carriers. A loading dock is located along the southern corner of this building.

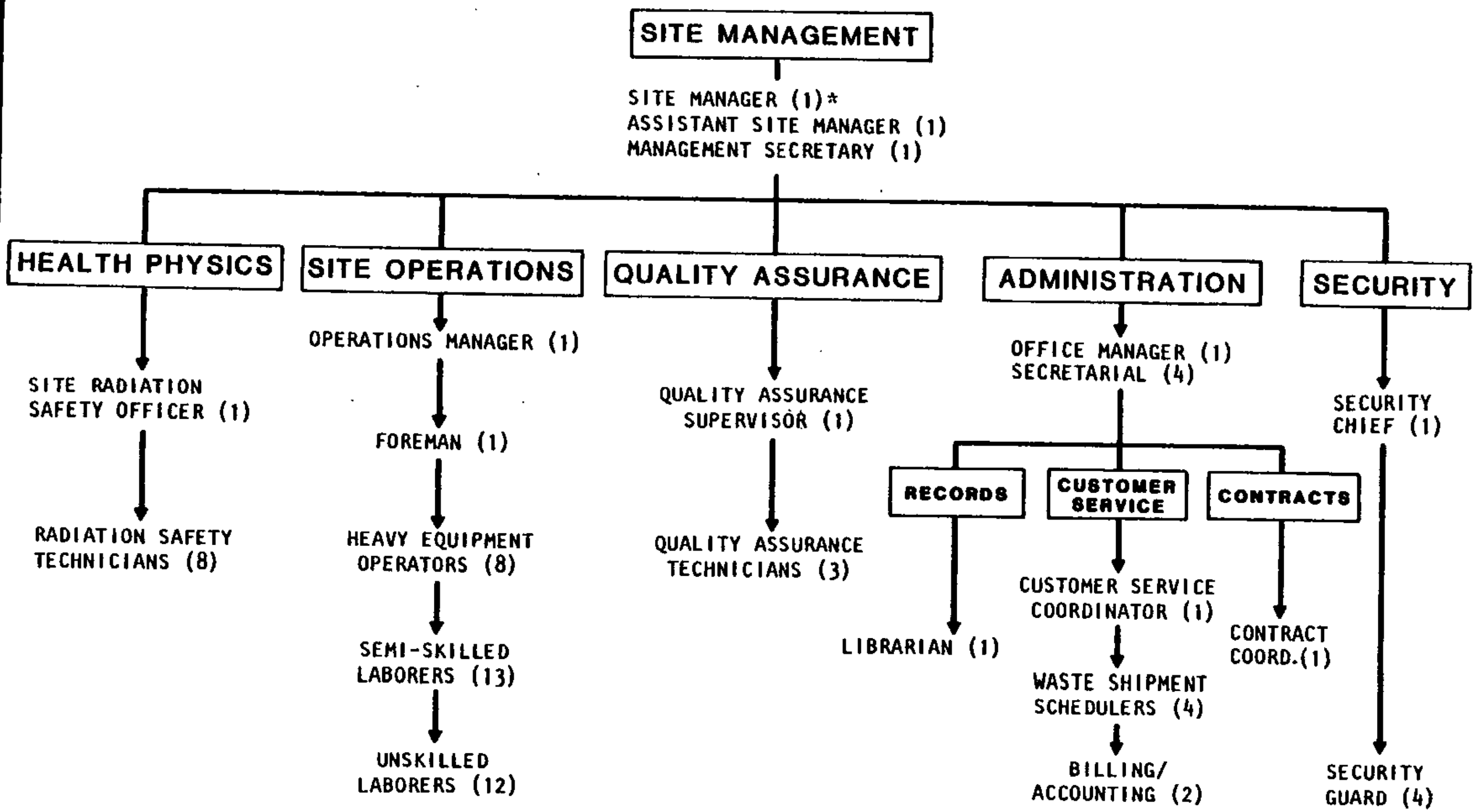
4.2.6 Storage Shed

A storage shed is used to store supplies and miscellaneous tools used at the disposal trenches. This shed is portable and is usually located close to the active disposal trenches.

5. SITE ADMINISTRATION AND OPERATIONS

5.1 Site Administration

The organizational structure of the reference disposal facility is described in this section. One of the primary functions of the site organization is to provide managerial controls for the safe handling of radioactive materials at the disposal facility. An organizational chart is included in Figure E.12, which has been developed considering administrational and organizational structures at existing disposal facilities. The organization chart does not



* NUMBER IN PARENTHESES EQUALS NUMBER OF PERSONNEL IN EACH JOB DESCRIPTION.

Figure E.12 Organization Chart - Reference Disposal Facility necessarily represent the sole or best manner in which the administration of a disposal facility may be organized. It does, however, provide a point of reference against which the operation of the facility may be described. Table E.4 contains a list of site personnel and their assumed annual salaries.

Table E.4 Reference Disposal Facility Payroll

No.	Job	Annual Salary($)	Extended Total($)
	Senior Staff		
1	Site Manager	40,000	40,000
1	Executive Secretary	12,000	12,000
1	Site Radiation Safety Officer	35,000	35,000
1	Assistant Site Manager	35,000	35,000
1	Foreman	28,000	28,000
1	Operations Manager	26,000	26,000
1	QA & Safety Supervisor	26,000	26,000
1	Office Manager	24,000	24,000
1	Security Chief	25,000	25,000
1	Librarian (Records)	12,000	12,000
1	Customer Service Coordinator	24,000	24,000
1	Contracts Coordinator	24,000	24,000
	Support Staff		
4	Waste Shipment Schedulers	16,000	64,000
2	Billing/Accounting Personnel	12,000	24,000
4	Security Personnel	12,000	48,000
4	Secretarial Personnel	9,000	36,000
	Staff		
3	QA Technicians	14,000	42,000
8	Radiation Safety Technicians	15,000	120,000
8	Heavy Equipment Operators	21,000	168,000
13	Semi-Skilled Laborers (includes mechanics)	15,000	195,000
12	Unskilled Laborers	10,000	120,000
70			$1,128,000

5.1.1 Corporate Management

The disposal facility is assumed to be operated for profit by a small corporation which is engaged in other nuclear-related business activities in addition to operating the disposal facility. The home office of the corporation is located offsite in another state. Overall control of radiation health and safety at the corporate level is under the control of the senior radiation safety officer, who is responsible for conducting periodic reviews of site operations for compliance with health and safety regulations and license conditions, including periodic site inspections and audits.

5.1.2 Site Management

Operations at the disposal facility are under the overall direction of the site manager and the assistant site manager. Beneath this level of site management, the administration of the disposal facility is organized into five parallel divisions: site operations, health physics, quality assurance (QA), administration, and security.

5.1.3 Site Operations Division

This division controls such activities as trench construction, waste handling and disposal operations, and site groundskeeping and maintenance, and is under the direction of the operations manager. The site foreman assists the operations manager and is in daily contact with the site labor force. The foreman is responsible for work assignments, crew coordination, maintaining proper operating readiness of equipment, and general supervision of onsite burial and maintenance operations. The work force, under the control of the operations manager and site foreman, is composed of 8 heavy equipment operators, 13 semi-skilled laborers, and 12 unskilled laborers. Heavy equipment operators are responsible for the operation and routine maintenance checks of equipment used at the site for waste disposal and maintenance operations. Semi-skilled laborers have a variety of functions at the site, including maintenance of site buildings and site property, operation of agriculture equipment, some heavy equipment operation, and some handling of waste material. Some of these laborers double as equipment mechanics when necessary. Unskilled laborers perform manual waste handling activities and other general support functions including maintenance of the facility buildings and grounds. The duties of the semi-skilled and unskilled laborers are rotated to control and minimize individual radiation exposures.

5.1.4 Health Physics Division

This division is under the direction of the site radiation safety officer (RSO), who is responsible for ensuring that proper radiation work procedures are used, that adequate monitoring for radiation hazards is provided, and that personnel training, equipment, and techniques provide control of radiation exposure during site operations. Besides the radiation safety controls, the RSO is also responsible for coordination of the site-safety training programs with the QA division, and for implementation of site emergency plans, procedures, and drills. The RSO reports directly to the site management as well as to corporate management, particularly the senior radiation safety officer.

Routine health physics functions such as environmental and personnel monitoring are conducted by the 8 health physics technicians under the supervision of the RSO. Their duties also include inspections of incoming and outgoing vehicles as well as site surveys for control of radioactive contamination.

5.1.5 Security Division

The primary responsibility of the security division is to control personnel and vehicle access to the site and to preclude potential theft of site tools or radioactive materials. The four-man security force is under the control of a security chief and performs such functions as checking personnel and visitors into and out of the disposal site, conducting periodic patrols of the grounds and the site perimeter, and maintaining communications with law enforcement and other offsite emergency personnel. Like the site RSO, the security chief has direct lines of communication with corporate management, particularly the senior radiation safety officer.

5.1.6 Administration Division

This division is responsible for routine office work under the supervision of the office manager, including coordinating shipments, maintaining records, and billing customers. As shown in Figure E.12, this division can be conceptually divided into three basic sections: records, customer service, and contracts.

Records are kept by a site librarian who maintains files and performs other functions including document reproduction, data recall, and coordination of routine reports. The 4 secretary/receptionists function as typists, file clerks, bookkeepers, and receptionists as needed by the various departments.

The customer service section coordinates the delivery of radioactive material to the site, schedules shipments, assesses charges for disposal services, and bills customers. The customer service section also informs customers of current disposal requirements and facility services which can be provided. Payment and accounting for routine site expenses is also handled by this section. The contracts section consists of a contract coordinator who works with corporate management and other site operational divisions to obtain needed outside services such as laboratory analyses, heavy equipment rental, transportation services, and utilities. The contract coordinator also arranges the use, as necessary, of outside consultants such as a registered surveyor.

5.1.7 Quality Assurance Division

The Quality Assurance (QA) program at the site is run by a QA supervisor who has three technicians under his supervision. The function of this division is to maintain compliance with applicable regulations, license conditions, and approved operational procedures, and has stop-work authority over site operations. Some of the site operations which are monitored by QA technicians include: trench construction, closure, site maintainance, waste disposal, equipment maintenance, and legal and procedural compliance by waste shippers and site personnel. Safety inspections, reviews of maintenance records, and training of site personnel are also included in their duties.

5.2 Site Operations

Site operations discussed in this section include: waste receipt, inspection, handling, storage, and disposal; radiation and contamination control; site groundskeeping and maintenance; environmental monitoring; security; record-keeping and reporting; and quality assurance.

5.2.1 Waste Receipt and Inspection

Shipments of radioactive waste arrive by truck (generally as sole use shipments but occasionally via common carriers) and are processed onto the site on a first come, first served basis. Accompanying the shipments are manifest documents--termed radioactive shipment records (RSRS)--which describe the content of the shipment. An example of an RSR used at one disposal site is included as Figure E.13. Arriving shipments are inspected for compliance with applicable federal regulations and waste acceptance criteria established as conditions in the disposal facility license.

Applicable federal regulations include those promulated by NRC in 10 CFR Parts 20 and 71, as well as those promulated by the Department of Transportation (DOT) in 49 CFR 170-179. DOT regulations contained in 49 CFR 170-179 have been recently incorporated into 10 CFR Part 71 by reference (Ref. 19). These regulations include, for example, waste packaging requirements, labelling requirements, vehicle placarding requirements, and allowable direct radiation and removable contamination levels at accessible surfaces of transport vehicles. Summaries of allowable direct radiation and removable contamination limits are included in Tables E.5 and E.6.

Waste acceptance criteria at existing disposal facilities vary somewhat from site-to-site. For purposes of this appendix, however, those waste acceptance criteria which are assumed for the reference disposal facility are provided in Table E.7. These reference criteria, which have been assumed considering license conditions at existing disposal facilities, include packaging criteria for liquid scintillation vials, absorbed liquids, and animal carcasses, as well as a limit on the amount of free standing liquid allowed in waste packages (Refs. 20-22). Other reference criteria included limits on the quantities of radioactivity that may be received and possessed onsite at any one time prior to disposal as well as package and shipment quantity limits for special nuclear material (Refs. 20-22).

The results of these inspections are recorded on radiation survey forms and summarized on the RSRs accompanying the waste shipments. Shipments found to be in compliance with federal regulations and license conditions proceed into the disposal area for unloading. Violations of transportation regulations are reported to federal and state authorities in compliance with federal and state regulations and license conditions. Damaged or leaking waste packages are identified and appropriate protective or remedial action is taken. Depending upon license conditions, damaged or leaking waste containers may be overpacked or repackaged, and either accepted for disposal or returned to the sender. Free-standing liquids detected are removed and solidified. Activities such as overpacking and solidification are performed at the waste activities facility.

SHIPPER: ____________________

ADDRESS: ____________________

PHONE: ____________________

SHIPMENT NO.: ____________________

DATE OF SHIPMENT: ____________________

CARRIER: ____________________

NO. 4064

PAGE ____ OF ____

☐ ____________________

TOTAL QUANTITY	PROPER SHIPPING NAME & HAZARD CLASS (PER 49 CFR 172.101)	TOTAL WEIGHT IN POUNDS
	Radioactive Device, N.O.S. – Radioactive Material	
	Radioactive Material, Fissile, N.O.S. – Radioactive Material	
	Radioactive Material, Low Specific Activity, N.O.S. – Radioactive Material	
	Radioactive Material, N.O.S. – Radioactive Material	
	Radioactive Material, Limited Quantity, N.O.S. – Radioactive Material	
	Radioactive Material, Special Form, N.O.S. – Radioactive Material	

(1) Item No.	(2) Cubic Feet	(3) Weight (Pounds)	(4) Physical Form	(5) Chemical Form	(6) Radionuclide	(7) Special Nuclear Material (Grams)	(8) Source Material (Kilograms)	(9) Activity ( ) Curies ( ) Millicuries	(10) Radiation Levels MR/HR Surface	(10) 3 Feet	(11) Transport Group	(12) Transport Index	(13)* Label	(14) Fissile Class	(15) Type of Container
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
													Radioactive –		
			TOTALS												

THIS IS TO CERTIFY THAT THE ABOVE-NAMED MATERIALS ARE PROPERLY CLASSIFIED, DESCRIBED, PACKAGED, MARKED AND LABELED AND ARE IN PROPER CONDITION FOR TRANSPORTATION ACCORDING TO APPLICABLE REGULATIONS OF THE DEPARTMENT OF TRANSPORTATION.

____________________ ____________________
Authorized Signature Title

THIS IS TO CERTIFY THAT ARTICLES ARE IN COMPLIANCE WITH ALL REGULATIONS APPLICABLE AT THE DESIGNATED DISPOSAL SITE.

____________________ ____________________
Authorized Signature Title

Figure E. 13 Example Radioactive Shipment Record

Table E.5 Radioactive Materials Maximum Radiation Level Limitations

Radiation level (dose) rate at any point on an external surface of any package of radioactive material may not exceed:

- 200 millirem per hour.
- 10 millirem per hour at three feet (transport index may not exceed 10).

Unless the packages are consigned to a "sole use" or "exclusive use" closed transport vehicle (except aircraft). Then the maximum radiation levels may be:

- 1,000 millirem per hour at 3 feet from external package surface.
- 200 millirem per hour at external surface of the vehicle.
- 10 millirem per hour at 6 feet from external surface of the vehicle.
- 2 millirem per hour in any position of the vehicle which is occupied by a person.

Source: 49 CFR 173.393 (i) and (j).

Table E.6 Radioactive Material Contamination Limits

Removable (nonfixed) radioactive contamination is considered significant if the level of contamination exceeds any of the following when averaged over any area of 300 cm^2 of any part of the package surface:

Contaminant	Maximum Permissible Level	
	uCi/cm^2	dis/min/cm^2
Natural or depleted uranium and natural thorium		
Beta-gamma	10^{-3}	2,200
Alpha	10^{-4}	200
All other beta-gamma emitting radionuclides	10^{-4}	200
All other alpha-emitting radionuclides	10^{-5}	22

Source: 49 CFR 173.397

Table E.7 Waste Acceptance Criteria for the Reference Disposal Facility

Basic Criteria

1. Receipt of waste containing transuranic radionuclides is restricted to waste streams containing less than 10 nanocuries total transuranic nuclides per gram of waste, provided that the transuranic radionuclides are essentially evenly distributed within a homogeneous waste form. Household smoke detectors containing Am-241 foils which may exceed the transuranic limit of 10 nanocuries per gram of material may be accepted for disposal provided that the entire detector is disposed.

2. Absorbed liquids may be received for disposal at the disposal facility provided that sufficient absorbent is used to absorb twice the volume of liquid. The container in which the absorbed liquid is shipped must be lined with a sealed plastic liner (minimum 4 mil thickness).

3. With the exception of liquid scintillation vials, other liquid-containing vials used for in vitro clinical or laboratory testing, and animal carcasses, no liquids may be received which have not been absorbed or solidified. Solidified and absorbed liquids shall contain less than 0.5% or one gallon of free-standing liquids per container, whichever is less.

4. Liquid scintillation vials and fluids, other liquid organics with similar chemical properties, and radioactive materials in individual units or vials (not to exceed 50 ml) used for in vitro clinical or laboratory testing may be received for disposal provided that the waste material is packaged in sufficient absorbent material to absorb twice the total volume of liquid. The container in which the waste material and absorbent is shipped must be lined with a sealed plastic liner (minimum 4 mil thickness).

5. Animal carcasses or other biological material must be layered with absorbent and lime and place within a sealed inner container which is then placed within a larger container having a capacity at least 40% greater than the inner container (e.g., a 30-gallon drum within a 55-gallon drum). The inner container must be completely surrounded by additional absorbent material and the outer container must be sealed.

6. Use of cardboard, fiberboard, and other paper packages for delivery of radioactive waste to the disposal facility is prohibited.

7. Chemically explosive radioactive material that might react violently with water or moisture may not be accepted for disposal at the site.

8. Gaseous Kr-85 and Xe-133 may be received for disposal provided that the disposal containers are either sealed sources or DOT specification cylinders. The internal pressure within a container may not exceed 1.0 atmosphere and the total activity contained within each container may not exceed 100 curies.

Table E.7 (continued)

Undisposed Possession Limits

The licensee may not possess (undisposed) at any time more than the following quantities:

1. 60,000 curies of byproduct material;
2. 80,000 pounds (36,000 kg) of source material; or
3. 5,000 grams of special nuclear material (SNM).

SNM Packaging and Shipment Limits

1. No single package shall contain more than 100 grams of uranium-235, or 60 grams of uranium-233, or any combination thereof, such that the sum of the ratios of the quantity of each special nuclear material to the quantities specified does not exceed unity--i.e.;

$$\frac{\text{grams contained U-235}}{100} + \frac{\text{grams contained U-233}}{60} \leq 1.$$

2. No single package may contain more than 15 grams of any combined uranium-235 or uranium-233 per cubic foot of total volume.

3. Each accumulation of packages (a shipment) shall contain not more than 500 grams of uranium-235 or 300 grams of uranium-233, or any combination thereof, such that the sum of the ratios of the quantity of each special nuclear material to the quantities therein does not exceed unity--i.e.,

$$\frac{\text{grams contained U-235}}{500} + \frac{\text{grams contained U-233}}{300} \leq 1.$$

4. Each accumulation of packages shall be stored at least 12 feet from any other package containing special nuclear material.

5.2.2 Waste Storage

Generally, waste received at the site is disposed of within a few days. Waste that must be temporarily stored is generally left in transport vehicles. There may be a reason, however, to temporarily store a few packages in a designated storage area, as when waste packages arriving by common carriers are stored temporarily. As it often takes considerable time to process a waste transport vehicle into and out of a disposal site, it is sometimes more convenient to drop off waste packages (and accompanying paperwork) received from common carriers at the site storage area. The waste can then be disposed at a later time.

An added storage requirement exists for wastes containing special nuclear material. (At the reference facility, special nuclear material is limited to uranium-233 and enriched uranium-235; no plutonium is accepted for disposal.) License conditions require that any single shipment of special nuclear material must be stored at least 12 feet from any other package containing special nuclear material.

5.2.3 Waste Disposal

Waste is randomly emplaced in the trench using cranes and forklifts, and backfilled with dirt removed during trench excavation. Random waste emplacement results in a trench volume use efficiency of about 50%. License conditions prohibit uncovered waste from extending more than 100 feet beyond the backfilled portion of the trench. License conditions also require that backfill operations commence immediately if radiation readings greater than 100 mr/hr are recorded at the trench boundary, and continue until radiation levels are reduced below 100 mr/hr. License conditions prohibit waste packages from being placed or standing in water, so waste disposal commences at the high end of the trench and works down towards the lower end. Rainwater falling within the open trench and contacting the uncovered waste packages drains away to the lower end of the trench. Rainwater collecting in the lower end of the trench is then removed as necessary and treated by such methods as solar evaporation or solidification.

Waste is emplaced to within one meter of the top of the trench. Earthen fill is then backfilled into the trench. A one meter thick cap composed of soil is then placed upon the backfill and is mounded. No special compaction is performed on the backfill and cap other than that provided by trucks and heavy earth moving equipment driven over the top of the cap. The cap is then covered with natural overburden material as necessary to provide good drainage characteristics and according to the final contours planned for the site surface. The overburden is then reseeded to promote growth of a short-rooted grass cover.

Similar to the storage requirements discussed above, an additional requirement exists for disposal of wastes containing special nuclear material. License conditions require that each package of waste containing special nuclear material be disposed of in such a manner as to have a minimum of eight inches of earth (or wastes not containing special nuclear materal) in all directions from any other package containing special nuclear material.

Following trench capping, the disposal trenches are each marked with a monument which is inscribed with the following information:

- A trench identification number;

- o Total trench activity of radioactive material in curies, excluding source and special nuclear material; mass of source material in kilograms; and mass of special nuclear material in grams;
- o Date of completion of waste disposal into the trench; and
- o Volume of waste in the trench.

In addition, each of the four top corners of the disposal trench are marked with a marker stone.

During waste handling and disposal, operations are monitored to ensure radiation safety. After the transport vehicle is unloaded it is again surveyed for contamination and decontaminated, as necessary, prior to leaving the restricted area. The results of the survey are recorded on the accompanying RSR.

5.2.4 Site Groundskeeping and Maintenance

Groundskeeping includes both the upkeep of grounds and the maintenance of external building surfaces. The purpose of groundskeeping is to promote site integrity by maintaining proper contour and soil conservation practices, by properly maintaining external structures and site systems, and by overseeing closed burial trenches in an efficient manner. Groundskeeping activities include contouring of the ground surface, emplacement of a soil cover material such as grass, fertilizing, mowing, etc.

A site maintenance program entails routine inspection of site surfaces and fences for trench settlement, gullying, damage, debris, etc. Repairs are made as necessary.

An important part of the reference facility site groundskeeping and maintenance program is surface water management. A surface water management program is site-specific (i.e., is dependent on each site's topography, amount of rainfall, etc.), but its overall purpose is to divert surface water resulting from precipitation away from open trenches and to allow the surface water to flow offsite in a manner which will minimize erosion. The reference disposal facility is assumed to utilize low berms around open trenches to help accomplish this.

5.2.5 Site Safety, Radiation, and Contamination Control

This section describes licensee programs, operations, and procedures at the reference disposal facility to ensure site safety and to minimize potential offsite releases of contaminants. Included in this discussion are methods used at the reference facility to:

- o maintain personnel exposures to levels in compliance with 10 CFR Part 20, and furthermore to levels as low as reasonably achievable (ALARA);

- o maintain releases of radioactive materials to unrestricted areas to levels in compliance with 10 CFR Part 20, and furthermore to levels ALARA;
- o monitor compliance with transportation regulations promulgated by the Department of Transportation (DOT) in 49 CFR 170-179; and
- o ensure industrial (nonradiological) safety at the site.

Many of the site procedures described in this section are utilized for a combination of reasons. For example, strict monitoring for compliance with DOT transportation regulations serves to help reduce site personnel exposures and site contamination levels in addition to reducing potential transportation impacts. Controlling site contamination to low levels reduces personnel exposures as well as minimizes potential offsite releases through liquid or airborne pathways.

The remainder of this section describes licensee methods to maintain site safety and to control radioactive materials at the disposal facility. To do so, this section has been divided into five subsections as follows:

- o personnel radiation monitoring;
- o site radiation and contamination control;
- o industrial safety;
- o abnormal or emergency situations; and
- o training.

5.2.5.1 Personnel Radiation Monitoring

Personnel radiation monitoring at the reference facility includes use of personnel monitoring devices, periodic internal monitoring, and administrative controls to ensure radiological safety.

Monitoring devices are worn by all site personnel who may become occupationally exposed to ionizing radiation. A long-term record of cumulative personnel exposures is maintained through the use of film or thermoluminescent dosimeter (TLD) badges. These are replaced, analyzed, and the resulting exposures reviewed and recorded on a periodic basis (usually on a monthly or quarterly schedule). In addition, monitoring badges are replaced and analyzed whenever there is reason to believe that an employee may have received an unusually high radiation dose. Pocket dosimeters are also worn by site personnel and are used to provide an indication of radiation exposures over shorter time periods. These basic monitoring devices may, depending upon the circumstances, be supplemented by additional equipment such as electronic dose ratemeters, finger or wrist monitoring badges, and/or continuous air samplers.

A periodic internal monitoring program is maintained for exposed individuals as a supplement to use of personnel monitoring devices (film badges, TLDs, and dosimeters). The internal monitoring program consists of an annual gamma scan for the lungs and thyroid in addition to a semiannual comprehensive bioassay. An immediate gamma scan and bioassay collection are performed if there is reason to believe that a site worker may have inhaled or ingested contaminated material. The gamma scan and bioassay is normally carried out at a nearby diagnostic laboratory. If through a site accident, a worker may receive an open wound and the wound is suspected of having become contaminated, a direct gamma scan is performed. Backup blood or wound swab samples are also collected and analyzed.

Administrative controls are used to maintain exposures to levels as low as reasonably achievable (ALARA). A baseline is established for each new site employee, which includes that employee's previous radiation exposure history. This baseline, quantified by an initial gamma scan and bioassay, is used to establish the employee's body burden prior to working at the site, and allows an evaluation of additional exposures received at the site. Records of subsequent occupational exposures are maintained, and an employee's functions are typically rotated to preclude individual employees from receiving a disproportionate share of exposure. Table E.8 provides an illustration of typical employee quarterly exposure levels at an existing disposal facility (Ref. 23).

5.2.5.2 Site Radiation and Contamination Control

The licensee conducts routine radiological surveys to detect removable contamination and fixed radioactivity, and to minimize the potential for spread of contamination or unnecessary exposure to radiation.

As discussed in Appendix E, Section 5.2.1, waste transport vehicles and waste packages arriving at the disposal facility are routinely inspected by health physics technicians for compliance with federal regulations and license conditions

Table E.8 Example Quarterly Exposures at an Existing Disposal Facility

Job Description	No. Personnel Monitored	Total Exp.* (rem)	Av. Exp. (rem)
Health Physics	10	3.312	0.331
Offloaders	26	11.745	0.452
Truck Drivers	8	0.221	0.028
Technical Services	5	0.066	0.013
Equipment Operators	6	3.128	0.521
Maintenance	12	0	0
Administrative Personnel	40	1.405	0.035
Contract Personnel	5	0	0
Total:	112	19.877	

Total Activity Disposed: 98,905.4 Ci

Total Volume Disposed: 12,500 m^3

*First quarter of 1979.

Shipments found to be in compliance with transportation regulations and license conditions proceed into the disposal area for unloading. Violations of transportation regulations are reported to federal and state authorities. Damaged or leaking waste packages are identified and appropriate protective or remedial action is taken. Vehicle offloading operations are monitored by a health physics technician(s) equipped with portable radiation survey equipment. Radiation levels at the edge of the active trench are controlled to levels less than 100 mr/hr. Should radiation levels exceed 100 mr/hr, the trench is immediately backfilled with earth or low-activity waste until radiation levels drop below 100 mr/hr. Waste transport vehicles leaving the disposal area are again inspected, surveyed, and decontaminated as necessary to comply with transportation regulations.

Routine housekeeping activities carried out at the site to minimize and control the spread of contamination include periodic surveys of site grounds, buildings, and equipment. Table E.9 summarizes an operational contamination monitoring program, including survey frequencies and contamination limits, currently used at an existing disposal facility (Ref. 21). This survey program is supplemented by the environmental monitoring program discussed in Appendix E, Section 5.6. Surveys or contamination control are also carried out whenever a site area or piece of equipment is used in a controlled area known to be contaminated or suspected of contamination through such possible events as a small spill.

Personnel procedures to control contamination and minimize exposures also include the use of anticontamination clothing and personnel surveys. At the reference disposal facility, waste handlers and other site personnel which may come into contact with radioactive materials are required to wear anticontamination coveralls, gloves, and other items as necessary. These are replaced when contaminated, and the used items are disposed as radioactive waste or sent offsite to a radioactive laundry service for decontamination. Site protective clothing may be supplemented by additional equipment such as additional anticontamination clothing, controlled air suits, or respirators if the situation indicates their use. All persons are required to conduct personal surveys ("frisking") for contamination upon leaving the restricted area as well as any other time the person has reason to suspect that he has become contaminated. Safety decontamination showers are provided for use if needed, and personnel decontamination is supervised by the site RSO if needed.

5.2.5.3 Industrial Safety

Radioactive waste disposal facility operators in the past have generally concentrated on radiation safety to the exclusion of a separate comprehensive industrial safety program. The radiation safety officer at the reference disposal facility doubles as the safety officer, and has one radiation safety technician assigned specifically to inspection of equipment and job safety practices and hazards safety control. A program of industrial safety paralleling the radiation program does not, however, exist at the reference facility. Rather, aspects of personnel safety such as use of protective clothing are generally meant to meet both radiation and industrial safety standards. For example, all radiological workers or personnel working with overhead equipment wear anticontamination coveralls, anticontamination gloves, protective hard hats, and safety-toe shoes. Workers are also trained in standard signals and alarms used on site equipment and by supervisory personnel, and follow specific work rules.

Table E.9 Survey Program and Operational Contamination Limits

Frequencies		Removable Contamination	Fixed Radioactivity
Radiation-Controlled (Restricted) Facilities or Buildings		Daily	Daily
Operational Trench		NA	Continuously (operational phase)
Site Grounds Outside--Operational Trench Area		NA	Weekly
Site Equipment		Weekly	Weekly
Nonradiation-Controlled (Nonrestricted) Facilities or Buildings		Monthly	Monthly
Waste Transport Vehicles		Arrival/Departure	Arrival/Departure
<u>Limits</u>			
Skin and Personal Clothing	alpha beta-gamma	0* 0	
Protective Clothing	alpha beta-gamma	0 1,000 dpm	
All Items for Unconditional Release	alpha beta-gamma	22 dpm/100 cm^2 220 dpm/100 cm^2	0.1 mrem/hr**
Sole Use Vehicles	alpha beta-gamma	220 dpm/100 cm^2 2,200 dpm/100 cm^2	0.5 mrem/hr**
All Site Areas, Facilities Equipment, Outside Restricted Areas	alpha beta-gamma	22 dpm/100 cm^2 220 dpm/100 cm^2	0.1 mrem/hr
All Site Areas, Facilities, Equipment, or Tools Inside Restricted Areas	alpha beta-gamma	220 dpm/100 cm^2 1,000 dpm/100 cm^2	0.5 mrem/hr

*Not detectable using survey instrumentation.
**At any accessible surface.

5.2.5.4 Abnormal or Emergency Situations

Procedures and specific actions are established at the reference facility to aid in quickly and safely handling abnormal occurrences or site emergencies. Abnormal occurrences may include events such as a minor injury or a minor spill of radioactive material. A minor injury may be addressed through use of first aid equipment contained in site vehicles and in the health physics offices. In the event of a minor spill, the radioactive material is recovered and disposed, and the area in which the spill took place is decontaminated.

Site emergencies are expected to occur much more infrequently than abnormal occurrences, but are also expected to be potentially more serious. Specific actions contained in site procedures for emergency situations may include efforts to minimize exposures and control the potential spread of contamination, use of additional anticontamination or respiratory equipment, communication with emergency or law enforcement agencies, notification of regulatory authorities, and filing follow-up reports.

Overall control of an emergency situation is the responsibility of the site RSO, who directs actions of radiation safety technicians and other site workers in addition to coordinating with site security. Site security personnel maintain communications with site personnel responding to an emergency as well as with offsite emergency organizations. A central communications control point is maintained in the site security office and from this point, site personnel can be directed in their actions via loudspeakers located in the administration and operational areas and by radio communications with site security vehicles. These are radio-equipped four-wheel drive vehicles containing emergency equipment such as respirators and anticontamination clothing. The radios can also be used to communicate with local offsite emergency services such as police, fire, and ambulance. A call tree is established at the facility for telephone communication with corporate and site management, site personnel, local offsite emergency services (police, fire, ambulance), federal emergency services (e.g., DOE regional coordinating offices for radiological assistance), and federal and state regulatory agencies.

In addition, existing federal regulations require timely notification of federal authorities for a number of types of abnormal occurrences or emergency situations, as well as follow-up reports. Specific notification and reporting requirements depend upon the severity of the incident and some of these requirements are set out in the following federal regulations:

10 CFR 19.13(d)	Notices, instructions, and reports to workers
10 CFR 20.402	Theft or loss of licensed material
10 CFR 20.403	Notification of incidents
10 CFR 20.405	Reports of overexposures and excessive levels and concentrations
10 CFR 70.52	Accidental criticality/theft/loss of special nuclear material
29 CFR 1904	Recording and reporting occupational injuries and illness

49 CFR 171.15	Immediate notice of certain hazardous materials incidents
49 CFR 171.16	Hazardous materials incident reports
49 CFR 177.861	Accidents involving radioactive materials

At the reference facility, a checklist is used to ensure that initial notification, follow-up reporting, and follow-up action implementation are completed within time limitations specified in the regulations. Data from these incident reports are used to evaluate and improve the site quality assurance and industrial safety programs.

The historical record does not contain evidence of accidents resulting in acute releases of radionuclides which would present a hazard to the public health and safety (Ref. 6). Nonetheless, specific site procedures addressing a number of different types of radiological and nonradiological emergencies are developed at the reference facility and drilled at least annually. These site procedures include planning for such potential events as major spills; treatment of irradiated, contaminated, injured, or contaminated and injured personnel; fires; bomb threats; and civil disorders.

Incidents such as a major spill would generally be expected to involve a transport vehicle or possibly a waste container accidently dropped from a crane. In this case, steps are taken to rope off and contain the contamination to a small area. The vehicle can then be decontaminated in a manner which minimizes personnel exposure.

Generally speaking, treatment for trauma, shock and hemorrhage takes precedence over personnel decontamination procedures and treatment of possible symptoms from irradiation. If an injured worker is in a high radiation environment, he is immediately removed from this environment concurrently with any other immediate life-saving actions that may be needed. The site is equipped with safety decontamination showers and first aid equipment, and some of the radiation safety technicians have additional training in emergency medical care. Prior arrangements have been made with a local hospital to receive injured personnel. If necessary, a site health physics technician may accompany ambulances to assist hospital personnel in further decontamination of injured site personnel.

For potential onsite fires, the main concern is the possibility of generating airborne radioactive material and the spread of contamination. A number of hand-held fire extinguishers are located on site vehicles and at a number of (stationary) site locations. Generally, a fire in a trench would be quickly extinguished by backfilling with soil. Personnel involved in the emergency use respiratory equipment and anticontamination clothing as appropriate. Local offsite fire fighting agencies may be called upon to assist. Arrangements are made by the site RSO to periodically review elements of basic radiation safety with these agencies.

5.2.5.5 Training

Pursuant to 10 CFR Part 19 of the Commission's regulations, each disposal site employee receives instruction in the hazards and controls of radioactive materials commensurate with the worker's duties and responsibilities for handling materials, and with the extent of anticipated worker exposure. This is combined with training in operational procedures to provide a solid basis for safe onsite work. Supplementary training to deal with site emergency conditions is also carried out. The worker is instructed at initial orientation, in the classroom, and under actual working conditions in a variety of subject areas. Each employee is certified upon the sucessful completion of each training subject area, and training records documenting the type of training received and the resulting scores are kept for a two-year period at the site. Periodic refresher training and recertification is required biannually after initial qualification. Example subject areas which have been covered in radiological worker training programs at existing disposal facilities include: (Refs. 24, 25)

Company and Site Organization
Principles of Radioactive Waste Disposal
Site Planning, Design, Security, Maintenance, and Operation
Interaction with Radiological Safety Staff
Site Radiation Work Rules
Waste Handling Procedures
Federal, State, and Local Regulations
Facility License and Possession Limits
Responsibilities of Employees and the Company
Forbidden Practices
Site Security
Warning Signs and Alarms
Basic Radiochemistry
Nuclear Interactions with Matter
Background Radiation
Modes of Exposure
Estimation of Dose Equivalent
Radiation Dose Limits
Biological Effects of Chemicals, Radioactivity, and Radiation
Basic Protective Measures
Anticontamination Clothing
Surveys
Radiation Exposure and Contamination Control
Emergency Procedures
Monitoring

5.2.6 Environmental Monitoring Program

An environmental monitoring program is carried out at the referenced disposal facility to monitor and control potential releases of radioactivity during site operations, to detect movement of radionuclides from the disposal trenches to the environment, and to provide information as to the long-term containment of radioactive waste disposed at the site. This is accomplished through an environmental sampling program in which samples are collected on the disposal site in addition to samples collected at a number of offsite locations. Potential exposure pathways to and possible impacts on individuals or local populations are also evaluated as part of the program.

Monitoring for potential long-term environmental releases is principally accomplished through well water samples obtained from both onsite and offsite wells, and from monitoring for the presence of water, if any, in trench sumps.

Monitoring for potential short-term operational releases of radioactivity is principally accomplished through collection of soil and vegetation samples, air samples, and samples collected to monitor direct gamma radiation levels. This portion of the environmental monitoring program is performed in conjunction and coordinated with the site survey program discussed in Appendix E, Section 5.2.5. (As discussed earlier, the survey program is a housekeeping activity involving periodic surveys of site grounds, buildings, and equipment for removable contamination and fixed radioactivity levels.) Information obtained from the environmental monitoring program is used to improve the effectiveness of the survey program and vice versa.

Potential short-term releases are expected to be minimal since site operations mainly involve handling of packaged wastes. However, some minor airborne releases may occur from pumping precipitation out of operational trenches followed by subsequent solar evaporation. Some minor airborne releases may also occur through operations (e.g., vehicle washdown, waste repackaging, liquid solidification) at the waste activities facility. These operations, however, are monitored by airborne sampling equipment. Experience has shown, however, that operational releases can be minimized through strict contamination control practices.

A summary of the operational monitoring program at the reference facility is included as Table E.10. This program includes collection of well water samples, soil and vegetation samples, and air samples, as well as monitoring for direct gamma radiation levels. Results from individual measurements recorded in the environmental monitoring program are retained for the life of the site along with information on sampling location and date, sample size (e.g., wet/dry weight), sampling and analytical procedures, units of data, and precision and accuracy associated with individual measurements. Additional information on the types of samples collected is presented below.

5.2.6.1 Well Water

Water samples are routinely collected from onsite monitoring wells, as well as offsite wells used by private residences. Onsite monitoring wells include 10 wells located along the perimeter of the restricted area as well as 15 wells scattered throughout the disposal area. The sample frequencies are semiannually for the boundary wells and quarterly for the disposal area wells. The samples are analyzed for gross alpha activity, gamma-emitting isotopes, and tritium as HTO.

In addition, the water level in each of the onsite wells is measured on a monthly basis to monitor fluctuations in the ground-water table. A total of five offsite wells used by private residents are also monitored on a semiannual basis. These wells are located both upstream and downstream of the ground-water flow beneath the site and are analyzed in a similar manner as the onsite monitoring wells.

Table E.10 Reference Facility Operational Monitoring Program

Sample Description	No. of Locations	Type	Media	Frequency of Analysis	Type of Analysis
External Gamma	50	Continous	TLD	Quarterly	Exposure
Atmosphere	3	Continous	Particulate Filter	Daily	Gross Beta-Gamma
			Particulate Filter	Weekly	Gamma Isotopic
			Charcoal Cartridge	Weekly	I-131
Soil & Vegetation	10	Grab	-	Quarterly	Gross Beta-Gamma Gross Alpha Tritium
Offsite Wells	5	Grab	H_2O	Semiannual	Gamma Isotopic Gross Alpha Tritium
Site Boundary Wells	10	Grab	H_2O	Semiannual	Gamma Isotopic Gross Alpha Tritium
Disposal Area Wells	15	Grab	H_2O	Quarterly	Gamma Isotopic Gross Alpha Tritium
Filled Disposal Trench Sumps	58	Grab	H_2O	Monthly	Gamma Isotopic Gross Alpha Tritium

*Trench sumps are checked on a monthly basis. Analysis would only take place if water was determined to be present in a sump

Filled and capped disposal trench sumps are checked on a monthly basis to determine if any water has collected. If any has collected, the water sample is analyzed for gross alpha activity, gamma-emitting isotopes, and HTO. The cause for any water collection is also immediately investigated and steps are taken to remove the collected water and prevent its reoccurrence. The number of disposal trench sumps monitored corresponds to the number of trenches constructed. By the time the site is closed, the facility is projected to contain 58 disposal trenches.

5.2.6.2 Soil and Vegetation

Soil and vegetation samples are collected at preselected locations in the disposal area on a quarterly basis. Analysis is performed on gross alpha activity, gross beta-gamma activity, and HTO. An annual gamma isotopic analysis is also performed. If the samples indicate significant levels of activity, additional samples are immediately obtained and analyzed. The cause of the elevated contamination levels are determined and the situation corrected.

5.2.6.3 Air

One low-volume, constant flow air sampler is operated continuously during disposal operations at a location nearby and downwind of the operating disposal trench. The sampler consists of a particulate filter which is analyzed daily for gross beta-gamma activity as well as a charcoal cartridge which is analyzed weekly for I-131. Additional grab samples are obtained and analyzed during abnormal occurrences such as a small spill. Two more air samplers are located in the waste activities building in the solidification area.

5.2.6.4 Direct Radiation

Direct radiation levels at the site are monitored through use of 50 TLD monitoring devices. Thirty-two TLDs are located along the boundary of the restricted areas. The remaining 18 TLDs are located in different parts of the administration and operational areas. One TLD is located in the administration building, 2 in the garage, 5 in the delivery vehicle parking area, 7 in the waste activities building, and 3 in the health physics/security building. The TLDs along the monitoring fences are replaced and analyzed on a quarterly basis. The remaining TLDs are replaced and analyzed on a monthly basis.

5.2.7 Security

The site security program is needed both for radiation health and safety considerations as well as to protect the many thousands of dollars worth of equipment, buildings, and facilities located onsite. The security program at the case facility is assumed to include the following:

- Full-time security personnel and a security training program.

- o Controlled access and exit from site areas including fencing and lighting, material gate passes, badge control, personnel and vehicle search procedures, lock and key control, etc.
- o Radio and telephone communication ability with emergency and law enforcement agencies.
- o Identification badges and dosimetry for site employees and visitors.
- o Procedures for notifying site personnel and local authorities in the event of an emergency in compliance with federal and state regulations and conditions.

Security personnel are assumed to interact closely with health physics personnel and carry out a number of functions which include checking people and vehicles into and out of the site, periodic patrols of site areas and fences, helping to respond to emergencies, and maintaining communications. Access to the restricted area is limited to employees, authorized unescorted visitors and contractors, visitors with escorts, and federal and state inspectors who require access to perform their duties. Site security equipment includes a few four-wheel drive vehicles which can be used to proceed to potential trouble spots if necessary. These vehicles are equipped with radios to communicate with each other and with a central security control point, and also contain emergency equipment such as anticontamination clothing.

5.2.8 Recordkeeping and Reporting

A number of records are assumed to be maintained at the site to cover the areas required by law, operational control, and for future use. Records which are assumed to be maintained at the facility include:

- o Personnel exposures
- o Waste receipt and disposal records
- o Personnel training records
- o Records for the QA program
- o Environmental monitoring data
- o Operating procedures
- o Records of site surveillance, and monitoring

Personnel exposures - Records are kept in compliance with NRC regulations contained in 10 CFR Part 20.

Waste receipt and disposal records - Records of waste disposal activities are generally retained permanently. These include the radioactive shipment records (RSRs) prepared by the shipper describing the name of the customer, waste package contents, radiation readings, results of shipment inspection for compliance with DOT transportation regulations, the dates of waste shipment receipt and disposal, and the disposal trench location (see Figure E.13). Some waste requires additional documentation because of more restrictive conditions placed on it.

Personnel training records - At the completion of each training program, the worker is certified and a record of the training course contents and results is kept. This information includes employee's name, social security number, expiration date, qualification date, contents of training program, final examination grade, date taken, and the instructor's signature as certification of successful course completion.

Environmental and personnel monitoring data - These records include offsite effluent and control station measurements, well water and stream water measurements, and extra measurements performed to more closely define a possible problem. Onsite workplace monitoring records for airborne, radiation field, and radioactive contamination hazards are maintained.

Records from the QA program - These include results of inspections, tests, audits, calibration records, records of nonconformance and their resolution, deviations, operating logs, and incident reports.

Records of site surveillance and monitoring - Surveillance and monitoring records are kept permanently, since the past history and trends indicated by these records are needed to verify the performance of the disposal facility.

In general, administrative records such as personnel files, internal office memos, preliminary designs and budgets, and other records of this type are not permanent and are assumed not to be retained longer than three years.

Reporting requirements include reporting periodic site inventory data, notices of shipper noncompliance, notices of abnormal events or license violations, personnel exposures, and environmental monitoring results to the appropriate regulatory agency or agencies. The licensee also complies with the reporting requirements of 10 CFR 70.54 (Nuclear Material Transfer Reports) for special nuclear material.

5.2.9 Quality Assurance

The quality assurance (QA) program at the site functions as a parallel department which provides quality control and training support to disposal operations. The QA personnel are not only familiar with the operating procedures, maintenance requirements, safety rules and basic radiation work procedures, but also have the responsibility to recommend improvements and coordinate the site training program. QA documentation is intended to provide adequate information to identify and correct substandard items, but is streamlined to the minimum required to achieve the objective. The QA program includes the following areas:

- personnel monitoring
- emergency drills and equipment
- contamination control
- working procedures
- site maintenance
- site groundskeeping
- waste receipt, inspection, storage, and disposal
- radiation instrument care and calibration

- o environmental monitoring
- o security
- o construction of disposal trenches
- o closure and stabilization
- o recordkeeping

In addition, a management audit program is carried out at least quarterly to maintain high standards of radiological control and safety and to ensure compliance with federal, state, local, and site license requirements. The program includes a review of operating procedures and past exposure records, facility inspections, and surveillance of work being performed. The senior RSO is directly responsible for the implementation of the audit program. The following areas are included in the management audit plans of a currently operating facility (Ref. 24):

- o Dosimetry Program
- o Radiological Control and Safety Program
- o Emergency Drills and Equipment
- o Operational Procedures and Performance
- o Personnel Decontamination
- o Radiological Survey and Posting
- o Radiation Instrumentation
- o Environmental Monitoring
- o Site Security

5.3 Facility Closure and Long-Term Site Control

This section briefly describes the assumed actions taken by the licensee to close the reference disposal facility and to prepare the facility for long-term care by the site owner. Following closure, long-term care activities by the site owner are also described. As discussed below, these activities are costly, and are principally a result of the compressible and degradable nature of much of the waste, and the practice at the reference facility of randomly and indiscriminately mixing this compressible waste with the other waste disposed into the facility. In addition, no special attention is paid to reducing the void volumes within the disposal trench and within the disposed waste packages through waste emplacement and trench cover compaction techniques.

The extensive long-term maintenance activities and high long-term care costs form a base case against which the costs and benefits of alternative waste forms and disposal facility design and operating practices are compared. In this way, the costs of alternative measures carried out during disposal facility operation to improve the stability of the facility may be compared against corresponding reductions in long-term care costs. Additional information is provided in Appendix Q, which develops cost estimates for facility closure activities as well as costs for various levels of long-term maintenance activity.

5.3.1 Reference Disposal Facility Closure

Final closure of the reference disposal facility is assumed to require approximately one year and mainly involves dismantling and decontaminating site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring. Initial closure activities are assumed to last approximately one year, which is followed by a somewhat indefinite period of time prior to license termination during which the grass cover over the final disposal trenches are established, the site is inspected prior to transfer to the site owner, etc.

Of the six buildings on the reference disposal facility, three of them--the administration building, the health physics/security building, and the site warehouse -- are located in the administrative area of the site and should be free of contamination. The administration building and the warehouse are dismantled and sold for salvage. The health physics/security building is left standing for use by the site owner during the institutional control period. Of the remaining three site buildings, only the waste activities building is expected to have appreciable levels of contamination. This building is decontaminated to the extent practical and demolished, as is the site garage. The site shed is decontaminated as necessary and is also left standing onsite for further potential use by the licensee and the site owner. To accommodate the waste produced during dismantlement and decontamination operations, either an additional small trench is excavated, or space is left in the last of the fifty-eight (58) large disposal trenches. The volume of waste produced during these operations is estimated to be relatively small--about 1130 m^3 (40,000 ft^3) (Ref. 26).

For the reference facility, there is assumed to be no efforts to recontour the disposal site land. The trench covers are left mounted. The final disposal trenches are filled, capped, graded, and seeded with a grass cover.

During this time period, the licensee makes a final survey of the disposal area to determine direct radiation levels. All parts of the disposal area are certified as having radiation levels at essentially background levels. A few hotter spots are observed but these are filled with overburden as necessary to reduce the radiation levels to background.

5.3.2 Institutional Controls

At this point, the disposal license is terminated and control of the site is transferred to the site owner. For this appendix, the site owner is assumed to be a state agency. Activities which take place during the institutional control period include site inspection and maintenance and site monitoring. Considerable maintenance activities are required during this time period, and mainly involve repair of slumping, subsidence and other disposal trench instability problems. Site maintenance is expected to be significant for 5 to 10 years after which the disposal areas begin to stabilize. During this phase, environmental monitoring of the disposal facility continues.

6. REFERENCE DISPOSAL FACILITY COSTS

This section presents a very brief summary of the cost assumed in this environmental impact statement for siting, designing, constructing, operating, and closing the reference disposal facility, as well as costs for 100 years of institutional control. The costs are summarized from the calculations in Appendix Q and may be presented in three segments:

1. Capital Costs, which include costs associated with siting, designing, licensing, and initial construction of the facility.

2. Operational Costs, which include costs associated with receipt and disposal of waste, as well as construction of disposal cells.

3. Postoperational Costs, which include costs for (a) facility closure, and (b) institutional control by a site owner.

To calculate total capital and total operational costs, "direct" capital and operational costs are first estimated. The costs are then each multiplied by parameters which account for additional indirect costs, cost of money, contingenity and profit.

Postoperational costs are broken up into closure costs and institutional control care costs. Closure costs are calculated assuming that funds for closure are provided for by the licensee through use of an investment fund (represented as a surcharge on received waste). The availability of funds for closure is assured by a mechanism such as a surety bond. As discussed in Appendix K, there are a number of mechanisms which could provide adequate assurance for site closure. These costs associated with these mechanisms are expected to be in the neighborhood of one to two percent of the principal. Institutional control costs are calculated based on the assumption that a state-operated sinking fund is established and that a surcharge is levied upon the waste received at the disposal facility on a cost per waste volume arrangement.

6.1 Capital Costs

Capital costs include all costs required to site, design, license, and construct a disposal facility; and include direct costs, indirect costs, and an annual fixed capital charge. Direct costs are costs which can be specifically assigned to particular tasks or actions, such as construction of a building or installation of a particular piece of equipment. Indirect costs are calculated as a percentage of the direct costs and are costs incurred during siting, licensing, and construction operations which cannot be specifically allocated to particular tasks or actions. The annual fixed capital charge is a fixed charge that occurs during the operating life of the facility, but is calculated as a percentage of the capital costs. It represents that portion of the total costs which are required during the (20 year) operating life to recover capital and interest expenses and to earn a specified return on a firm's equity.

6.1.1 Direct Capital Costs

For the reference disposal facility, the following items are included as direct capital costs, in 1980 dollars:

Capital Outlay	1980 $ (X1000)
1. Site selection	$ 500
2. Environmental impact studies	600
3. NRC licensing fees	325
4. Other licenses and permits	250
5. Land acquisition (200 acres @ $1200/acre)	240
6. Corporate administration	1,625.25
7. Construction administration	450.45
8. Legal fees	1,000
9. Road construction	200
10. Initial land preparation (40 acres @ $1145/acre)	45.8
11. Office and other miscellaneous light equipment	400
12. Building construction	1,173.25
13. Utilities and supplies during construction	175
14. Peripheral systems (fencing, lighting, utilities installation, telephone, etc.)	300
15. Engineering and design (10% of items 9, 12, and 14)	167.3
	$ 7,452.

In the analysis, the required direct labor costs are assumed to be included as part of construction operations. Costs for site selection, environmental impact studies, and licenses and permits are assumed to be constant for all the alternatives considered. Adminstrative and legal costs are also assumed to be constant. The costs for buildings, structures, and other site construction activities, however, are a variable depending upon the alternatives considered. Equipment used to construct disposal cells (e.g., disposal trenches) to dispose of received wastes, and to carry out support activities are not included as part of the capital costs but are included as equipment leasing charges through the operational life of the facility.

Building costs, which include the costs of labor required for construction, are assumed to vary depending upon the complexity of the activities taking place within the particular building. These costs are estimated as follows:

Building	1980 $
Administration	$ 235,400
Health physics/security	387,500
Warehouse	126,500
Garage	113,000
Waste activities	302,250
Storage shed	8,600
	$1,173,250

Engineering and design costs are assumed to be 10% of the costs for road and building construction and installation of peripheral systems (fencing, lighting, utilities, monitoring wells, telephone connections, etc.). These costs include the costs associated with consulting, quality control, and inspection fees.

Estimated costs for corporate administration during facility siting, design, licensing, and construction are assumed to persist for 5 years. During initial construction of the facility, which is assumed to last one year, additional manpower is required to oversee site activities, to coordinate contracts, and to arrange for waste shipment customers. All personnel charges are increased from the basic rates by addition of a 10% fringe charge. A 50% overhead is then calculated from the combined base and fringe charges. Legal fees during facility siting, licensing, and construction are assumed to average approximately $200,000 per year for each of the five years.

6.1.2 Indirect Capital Costs

Indirect capital costs are expenses of a general nature which apply to the overall project of siting, licensing, designing and constructing the disposal facility, and are calculated as a percentage of the direct capital costs. For the purposes of this environmental impact statement, the indirect costs are estimated as follows:

Item	Percentage of Direct Costs
Interest during construction	33
Contingency	30
Other Costs	10
	73 %

Interest during construction charges include the sum of interest charges for capital expenditures. It covers the net cost of funds utilized to finance the siting, design, and construction of the facility.

Contingency costs cover any additional (unplanned for) costs that may arise during siting, licensing, and constructing the disposal facility. An example is the possible need to acquire additional hydrogeologic data regarding the proposed disposal facility. Other costs cover miscellaneous overhead expenses during the preoperational phase such as insurance, sales tax on purchased equipment and material, and so forth.

6.1.3 Annual Fixed Capital Charge

The annual fixed capital charge includes such items as interest on borrowed money, return on equity, depreciation, taxes, and insurance. Calculation of annual fixed charges for an actual disposal facility can become quite complicated;

however, for the purposes of this appendix these charges are assumed to be calculated as a constant fixed percentage (25%) of the initial total investment cost, carried out over the 20-year operating life of the facility.

6.1.4 Total Capital Costs

Total capital costs are estimated as the product of the total capital investment times the annual fixed change rate over a period of 20 years, times a profit margin. For the purposes of this appendix, a profit margin of 20% is assumed. Therefore,

Total capital costs = Direct costs X indirect costs X annual fixed charge X profit.
= Direct costs X 1.73 X 0.25 X 20 X 1.20
= 10.38 direct costs

For the reference disposal facility,

Total capital cost = 10.38 ($7,452,050)
= $77,352,300.

6.2 Operational Costs

The operational costs consist of the labor, equipment, materials and supplies required to conduct waste receipt and disposal activities. Included in these costs are overhead, contingency and profits, as well as costs for environmental monitoring. The necessary costs for providing financial guarantees such as security bonds or letters of credit are included under postoperational costs. While they are incurred during operations, they are a function (as based on annual premiums) of the projected postoperational costs.

6.2.1 Direct Operational Costs

A summary of the direct operational costs over the 20-year life of the disposal facility are as follows:

Operating Costs Over 20 years (X 1000)	
1. Operations and maintenance (10% of buildings, facilities, and light equipment over 20 years)	4,626.5
2. Disposal cell materials (58 trenches)	124.2
3. Heavy equipment	12,228
4. Payroll:	
o Base	22,560
o Fringe	2,256
o Overhead	12,408
5. Corporate administration (@ $300 k/yr)	6,000
6. Legal fees (@ $150 k/yr)	3,000
7. Environmental monitoring	534
8. Regulatory costs	1,138
9. Consumables (utilities, fuel, supplies, etc.) (@ $200 k/yr)	4,000
	$68,875

Operations and maintenance costs include costs associated with routine operation and maintenance (upkeep) of site grounds, office and miscellaneous other light equipment, buildings, site facilities, and other structures such as roads, fences, lighting, etc. These costs are estimated at 10% of the capital outlay for these grounds, buildings, facilities, and other structures per year.

Disposal cell construction takes place continuously during facility operation. Construction operations include clearing away existing foliage, excavation of disposal cells, installation of standpipes and French drains, backfilling and compacting with heavy machinery, seeding and mulching, and emplacement of markers and monuments. Costs for disposal cell construction include those associated with equipment use (including fuel and lubrication), labor, and materials. For the reference facility, labor and equipment costs are included as part of costs for payroll, heavy equipment leasing, and consumables.

Equipment leasing costs are costs required to lease construction and waste handling equipment for use at the site (e.g., cranes, trucks, tractors, fork lifts, etc.) over a 20-year facility operating life. Operators of an actual facility will actually own part of the equipment and lease part of the equipment used at the facility. Assuming that the equipment is owned would require developing a number of additional assumptions regarding the fraction of owned equipment, how it was purchased (new, used), the financial arrangements regarding the purchases, and the operating life of the equipment prior to replacement. For this appendix, then, it is more straightforward to assume that all equipment is leased.

Corporate administrative costs are estimated at an average of $300,000 per year over the operating life of the facility. In addition, legal fees are estimated at an average of $150,000 per year.

Payroll costs are the largest component of the total expenses incurred during site operations. Payroll costs include personnel directly involved in the disposal operations, as well as site administrative and support personnel. The assumed payroll costs per job function are listed in Table E.4. A 10% fringe is added to the base personnel costs; a 50% overhead is then calculated from the base and fringe charges.

Environmental monitoring costs involve costs associated with analysis of environmental samples collected as part of the facility environmental monitoring program. The assumed operational environmental monitoring program for the reference facility is shown in Table E.10. All gamma-isotopic, HTO, and I-131 sample analyses are assumed to be performed using offsite services.

Regulatory costs include costs associated with license renewals, inspection fees, and amendments.

Consumables (utilities, fuel, supplies, etc.) are estimated at $200,000 per year.

6.2.2 Indirect Operational Costs

Indirect operational costs are approximated as a percentage of the total direct operational costs and are assumed to consist of a 30% contingency allowance as well as a 20% profit.

6.2.3 Total Operational Costs

Total operational costs are estimated as the following:

$$\begin{aligned}\text{Total operational costs} &= (1.2)(1.3)(\text{direct costs}) \\ &= 1.56\ (\text{direct costs})\end{aligned}$$

For the reference disposal facility, total capital and operational costs equal the following:

$$\begin{aligned}\text{Total Costs} &= 10.38\ (\text{direct capital costs}) \\ &\quad + 1.56\ (\text{direct operational costs}) \\ &= 10.38\ (7{,}452{,}100) + 1.56\ (\$68{,}875{,}000) \\ &= \$184{,}797{,}000 \\ &= \$185./m^3 \\ &= \$5.23/ft^3\end{aligned}$$

6.3 Postoperational Costs

Postoperational costs are composed of two components: (1) costs for facility closure following the end of the facility 20-year operating life, and (2) costs for institutional control of the facility after closure. In this appendix, costs for closure are assumed to be borne by the licensee. However, to ensure that funds will be available to implement closure should for some reason the site is closed earlier than scheduled, the projected costs for closure are assumed to be covered by a surety mechanism obtained by the licensee. Funds for institutional control costs, however, are assumed to be obtained through a surcharge ($ per m^3 of waste) placed upon the waste received at the facility. Monies obtained through the surcharge mechanism are placed in an interest-bearing state operated investment fund.

6.3.1 Closure

Closure activities involve final decontamination and dismantlement of buildings and other structures, as well as preparation of the disposal facility for institutional control by the site owner. As an illustration in Appendix Q, two levels of closure costs are estimated: low and high. The low scenario is summarized below.

Final closure of the reference facility is assumed to require approximately two years and mainly involves dismantling and decontaminating site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring. A summary of the estimated costs are as follows:

Summary of estimated closure costs ($x1000)	
1. Building demolition	300.0
2. Waste disposal materials and survey	1.3
3. Personnel	503.3
4. Consumables	30.5
5. Equipment	120.6
6. Environmental monitoring	53.4
	$1,009.

Based upon consideration of the site closure and stabilization plans of an existing disposal facility, building demolition is estimated to cost approximately $300,000, assuming that a private contractor is hired to perform these operations. Building demolition, waste disposal, and most of the final site preparation is assumed to require approximately a year's effort. However, another year at reduced licensee effort is assumed to be needed for final site surveillance activities prior to license termination. Supplies and utilities are estimated as 10% of base personnel costs. Environmental monitoring costs are estimated assuming that the operational environmental monitoring program is continued during the closure period.

Total closure costs for the reference facility (assuming a low level of closure activities) are estimated at about $1 million in 1980 dollars. However, to estimate the closure costs at the end of the 20-year operating life, the costs are increased to account for inflation during that period. In addition, the licensee is assumed to accrue funds for closure through the operating life of the disposal facility through use of a surcharge ($ per m^3 of waste) on the waste received at the disposal facility. Monies collected through this surcharge mechanism are assumed to be set aside and invested into an interest-bearing fund. To assure the availability of funds for closure should the disposal facility close earlier than expected, the closure costs are also assumed to be protected by a surety mechanism. In Appendix Q, the total unit closure costs to the disposal facility customer are estimated as follows:

$$UCC = \frac{IT_o \quad (1+j)^{IT_o}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o}-1]} \right\}$$

IT_o = site operational life (years)

V_w = volume of waste

C_{80} = closure cost in 1980 dollars

i = average interest rate

j = average inflation rate

f = annual fee for assuring availability of closure funds.

For the reference facility, IT_o is 20 years, V_w is one million m^3, i is assumed to be 10%, j is assumed to be 9% and f is assumed to be 1.5%. This results in a total inflated closure cost (at year 2000) of $5.6 million and a unit cost to disposal facility customers of $3.64/m³ (10¢/ft³).

6.3.2 Institutional Control

For the cost estimates, 3 levels of institutional control are assumed: a high level, a moderate level, and a low level. For each level, costs are broken down into two basic activities:

- o recordkeeping and administrative support; and
- o site surveillance and maintenance (assumed to be contracted by the state agency to individuals or to a private firm)

Recordkeeping and administrative support costs are calculated by estimating the number of man-hours required by the state to administer the long-term care of the facility. The level of effort expended by the state is assumed to be a function of the degree of stability at the facility, and the level of surveillance, maintenance, and monitoring activities required for the facility. Administrative support costs include personnel salaries, overhead, utilities, etc., and are basically an estimate of the average cost to a government of one year's labor by a government employee. An approximate figure of $50,000 per man-year is assumed for a state employee.

Disposal facility surveillance and maintenance costs are calculated assuming that a company or individuals are contracted by the state for surveillance, maintenance, and environmental monitoring activities. These costs are assumed to include costs for:

- o personnel;
- o personnel fringe and overhead;
- o supplies;
- o equipment;
- o environmental monitoring sample analysis; and
- o contractor fees.

As long as the disposal facility is in a stable condition, then the long-term care activities could involve persons whose role would be little more than that of a caretaker. These activities could involve facility inspections, collecting environmental samples for analysis, and minor maintenance (if required) of fences, site grounds, and so forth. These activities would probably require some, but not extensive, knowledge of radiation, radiation safety, and radiation equipment.

However, if modest to extensive subsidence were a recognized problem, or if there was concern that subsidence was a potential problem, then much greater experience with radiation and contamination control and radioactive waste management would be needed. In these cases, a company experienced in radioactive waste disposal is assumed to be contracted to run the facility. The need to employ the services of such a company and the need to employ the company more-or-less full time at the facility results in considerable additional expenses to the state. Expenses would include personnel payroll and overhead, supplies, equipment and contractor's fees.

Supplies are estimated by assuming that the costs for the supplies needed are a fraction (10%) of the base personnel salaries. The more personnel are required to operate the site, the greater the outlay for supplies and utilities is likely to be. Equipment costs are geared to the level of effort by onsite personnel, and by the size of the work crew.

Environmental monitoring costs are estimated by again assuming 3 levels of environmental monitoring needs depending upon the stability of the facility--i.e., a high level, a moderate level, and a low level. A facility which requires a great deal of maintenance would also require a high environmental monitoring effort. This is because there are more activities at the site which might involve handling radioactive material, in addition to an inherent increased level of concern regarding the long-term impacts of an unstable site. On the other hand, monitoring costs would be expected to be significantly reduced at a stable site.

The fee is again assumed to be a fraction of the contractor's total expenses at the facility. In this case, as maintenance activities are assumed to involve a relatively low level of business risks, the fee is assumed to be 10% of the total expenses.

A summary of the costs over 100 years of institutional control, including state administration costs, as well as costs for site personnel, supplies, equipment, monitoring, and the contractor's fee is presented as Table E.11. As shown, for each level of institutional control activities, costs for 3 time periods are presented. The time periods considered are 0 to 10 years, 11 to 25 years, and 26 to 100 years. The different time periods are presented due to the expectation that the disposal facility would tend to naturally stabilize over time. This is similar to the approach taken by Battelle-Pacific Northwest Laboratories (PNL) in NUREG/CR-0570 (Ref. 10).

The low-level of maintenance costs are in the same range as the PNL projections for minimal long-term care costs at an eastern site over 100 years (Ref. 27). However the estimated costs may be conservatively high. As long as there is assurance that the facility is in a stable condition, it may be possible to get by with considerably less expenditures.

The estimated costs for the high level of maintenance, however, may be too low and contingency is assumed for unforeseen events. Unforeseen events could include water management problems ranging from periodic withdrawal of water

Table E.11 Estimated Annual Institutional Control Base Costs

Level of Effort	Adm	Contractor Costs ($k, per year) Personnel	Supplies	Equipment	Monitoring	Fee	Total
High							
0-10	150	179.85 (high)	10.9	53.4 (high)	19.2 (high)	26.3	439.65
11-25	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
26-100	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
Moderate							
0-10	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
11-25	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
26-100	50	33 (care)	2.0	- (nil)	3.1 (low)	-	88.1
Low							
0-10	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
11-25	25	33 (care)	2.0	- (nil)	3.1 (low)	-	63.1
26-100	12.5	33 (care)	2.0	- (nil)	3.1 (low)	-	50.6

from disposal trenches and solidification, to large scale dewatering activities brought about by an extensive occurrence of the bathtub effect.

Three levels of additional (contingency) costs are developed in Appendix Q and are estimated to range from approximately $1.7 million to $10 million. At a site with very permeable soils, water accumulation may not be a special problem, and additional costs could be just those associated with restabilization--i.e., $1.7 million ($167,800/yr).

At sites with moderately permeable soils, additional long-term costs could include those for a moderate amount of liquid treatment and a restabilization program. Assuming 10 years of moderate leachate treatment activities along with a restabilization program, total costs over 10 years could be as much as 3.67 million $367,000/yr.

For disposal facilities with very impermeable soils, experience has indicated that it is possible to create a situation where an extensive liquid treatment operation is required. Ten years of such treatment combined with a restabilization program could increase costs by about $10 million ($1,006,900/yr).

To determine institutional control costs over 100 years, the effects of inflation and interest must be considered. These effects are considered in Appendix Q and a formula is derived to estimated total long-term care costs. These may be converted to unit costs ($/m) simply by dividing by the volume of waste disposed. In Appendix Q, the long-term care costs are given as follows, where:

$$\text{Costs} = \frac{IT_o \, PV_{80} \, (1+j)^m}{[(1=i)^{IT_o} -1] \, (1+i)^{IT_c}} \text{, where}$$

IT_o = site operational life (years)

IT_c = closure period (years)

$m = IT_o + IT_c$

C_{80} = closure costs (1980 dollars)

i = nominal interest rate (expressed as decimal - e.g., 9% = 0.09)

j = inflation rate (expressed as decimal)

PV_{80} = present value of institutional control in 1980 dollars

$$= C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+j)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n} \text{, where}$$

For the reference facility, total institutional control care costs are calculated assuming a high level of long-term care costs and a moderate contingency level. Assuming that IT_o is 20 years, IT_c is 2 years, i is 10%, j i=s 9%, the values for C_a, C_b, and C_c are as given in Table E-11, and the contingency is $367,000 per year for ten years, then the total institutional control cost is $34.6 million, or $34.6/m³ (98¢/ft³). Higher costs would be expected for disposal facility sites where there is a potential for a severe bathtubbing problem.

REFERENCES

1. Papadopulos and Winograd, Storage of Low-Level Radioactive Wastes in the Ground, Hydrogeolgic and Hydro Chemical Factors, USGS Open-File Report 74-344, prepared for U.S. EPA, 1974.

2. DeBuchananne, G.D., Geohydrologic Considerations in the Management of Radiocative Waste, Nuclear Technology, Vol. 24, December 1974.

3. NRC, The Shallow-Land Burial of Low-Level Radioactive Contaminated Solid Waste, National Research Council - National Academy of Sciences, Washington, DC, 1976.

4. Peckham, Belter, Considerations for Selection and Operation of Radioactive Waste Burial Sites.

5. NRC, Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NUREG-0116, October 1976.

6. NRC, Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, NUREG-0216, March 1977.

7. Environmental Protection Agency, Final Rule: 40 CFR Part 257, Criteria for Classfication of Solid Waste Disposal Facilities and Practices, Federal Register, 44 FR 18138-18148, March 26, 1979.

8. EPA, Draft Environmental Impact Statement on the Proposed Guidelines for the Land Fill Disposal of Solid Waste, U.S. EPA, March 1979.

9. EPA, Proposed Regulations: 40 CFR Part 250, Hazardous Waste Guidelines and Recommendations, Federal Register, 43 FR 58946-59028, December 18, 1978.

10. EPA, Final Regulations: Hazardous Waste Management System (Hazardous Waste and Consolidated Permit Regulations), Federal Register, 45 FR 33066-33588.

11. Executive Order 11988, Floodplain Management, May 24, 1977.

12. Executive Order 11988, Protection of Wetlands, May 24, 1977.

13. Water Resources Council, Floodplain Management: Guidelines for Implementing Executive Order 11988, Federal Register, 43 FR 6030-6055, February 10, 1977.

14. Water Resources Council, Guidance for Floodplain Management, Federal Register, 42 FR 52590-52599, September 30, 1977.

15. Keros Cartwright, et al., Geological Considerations in Hazardous Waste Disposal in Illinois, Illinois Institute of Natural Resources, State Geological Survey Division, May 21, 1979.

16. Maine Department of Environmental Protection, Proposed Solid Waste Managemer Regulations, August 26, 1980.

17. NRC, Uranium Mill Licensing Requirements, Federal Register, 45 FR 65521, October 3, 1980.

18. Fenn, D. G., K. J. Hanley, and T. V. DeGeave, Use of the Water Balance Method For Predicting Leachate Generation From Solid Waste Disposal Sites, U.S. Environmental Protection Agency Report SW-168, 1975.

19. U.S.NRC, 10 CFR Part 71 Packaging of Radioactive Material for Transport of Radioactive Material Under Certain Conditions. Shipment in Accordance with Department of Transportation Regulations, Federal Register 44 CFR 63083 November 2, 1979.

20. South Carolina Department of Health and Environmental Control, Radioactive Materials License No. 097, Amendment No. 28, November 17, 1980.

21. Washington State Department of Social and Health Services, Radioactive Materials License No. WN-IO 19-2, January 11, 1980.

22. Nevada Department of Human Resources, Radioactive Materials License 13-11-0043-02, October 26, 1979.

23. Chem-Nuclear Systems, Inc., Environmental Assessment for Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, January 1980.

24. Nuclear Engineering Company, Inc., Radiological Controls and Safety for Burial Sites Manual, Docket No. 27-48, November 4, 1976.

25. Chem Nuclear Systems, Inc., Quality Assurance and Procedures Manual, Docket No. 27-47, January 6, 1978.

26. Chem Nuclear Systems, Inc., Preliminary Site Stabilization and Closure Plan for the Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, May 1980.

27. Murphy, E.S., G. M. Holter, Technology, Safety, and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570 Pacific Northwest Laboratories for NRC, June 1980.

APPENDIX F

ALTERNATIVE DISPOSAL TECHNOLOGIES

1. INTRODUCTION

A description of a reference near-surface disposal facility located in a humid environment in the eastern United States is provided in Appendix E. The reference facility is used to determine base case costs and impacts against which the costs and impacts of alternative waste forms as well as alternative disposal facility designs and operating practices can be assessed. Alternative waste forms considered in this environmental impact statement are addressed in Appendix D. Alternative disposal facility design and operating practices are addressed in this appendix. Costs for these alternative design and operating practices are developed as incremental costs to those associated with the design and operating of the reference facility as described in Appendices E and Q. Postoperational costs are not addressed in this appendix but are considered as part of the analyses in Chapter 5 of this EIS.

A number of variations in near-surface disposal techniques are discussed in Section 2. The discussion in Section 2.1 serves to provide a frame of reference to the later sections by reviewing ways in which designs may vary depending upon specific site characteristics. The remainder of Section 2 is devoted to discussion of alternative near-surface disposal technologies which can be used to improve long-term site stability and to reduce potential long-term impacts from: (1) potential inadvertent intrusion by humans, plants, or animals, and (2) long-term environmental releases and impacts. Many of the alternatives considered also have potential resultant impacts upon site operational safety--principally radiation exposures to site personnel--and these potential impacts are also discussed when appropriate.

Section 3 addresses land disposal alternatives to near-surface disposal, including intermediate depth disposal and mined cavity disposal. Section 4 reviews disposal technology options other than land disposal, including ocean disposal, and extraterrestrial (space) disposal. In Section 5, differential costs for the disposal technology options considered in this appendix are presented. These costs are calculated in a similar manner and consistent to the cost analysis for the reference disposal facility presented in Appendix Q. Finally, Section 6 provides a list of references to this appendix.

2. ALTERNATIVE NEAR-SURFACE DISPOSAL TECHNOLOGIES

2.1 Design Variations Related to Specific Site Characteristics

A reference disposal facility having a conceptual site design (e.g., trench size, facility layout) that is representative of existing disposal facilities has been described in Appendix E. The actual design of a particular disposal facility, however, can be influenced by site-specific conditions. Three design elements of disposal trenches which can be influenced by the characteristics of a particular site are trench dimensions, slopes of excavations, and final grades. Additionally, variations in dimensions and slopes can influence the overall disposal costs.

Trench Dimensions

As the dimensions of an excavation increase, the land use efficiency of using the excavation for waste disposal increases. For example, if the base case trench planar dimensions (180 m x 30 m) are doubled (to 360 m by 60 m), the land use efficiency is raised by about 6% (from 9.45 ft^3/ft^2 to about 10 ft^3/ft^2). If the planar dimensions are tripled, an increase in land use efficiency of nearly 8% can be realized. (The land use efficiency is defined as the volume of waste that is disposed per unit land area, including the area separating the individual disposal cells. Only land suitable for disposal is considered in this calculation. Land area set aside for administrative functions, borrow areas, and other areas not specifically used for placement of waste in near-surface excavati(are excluded from this calculation.)

Expansion of trench planar dimensions will require additional expenditures of money for excavation, but the increased land use efficiency results in a decrease in the land area commited for waste disposal. If gentle side slopes are required for safe construction and operation of the facility (as indicated by the nature of the existing soils), the positive effect on land use efficiency achieved by increasing trench dimensions becomes even greater. However, when a trench width is increased substantially, a major asset of trench disposal is diminished in strength--i.e., the direct radiation shielding provided by the walls of the trench and the waste packages within the trench. The narrower the trench, the greater the radiation shielding to facility workers that can be generally achieved. As the width of a trench becomes a large multiple of the depth, radiation "shine" from waste packages can become a problem. In addition, as the trench width is increased, the ease of waste emplacement from outside of the trench is diminished. Eventually, as the trench width increases it becomes first impractical and then impossible to emplace waste from outside of the trench. Waste emplacement activities must then be carried out from inside the trench, resulting in increased occupational exposures. When waste emplacement is performed within the trench, trench design, trench construction, and waste emplacement operations are also affected. For example, at the reference disposal facility described in Appendix E, each trench is equipped with a ramp which is occasionally used to facilitate placement of waste packages by forklifts. For a very wide trench, two or more ramps may be required to accommodate a steady flow of waste emplacement vehicles (e.g., forklifts) through the trench. These ramps would be used routinely, as opposed to intermittently as they presently are at most commercial disposal sites.

The mode of trench construction would also be generally modified as the size of the excavation is increased. For example, a silt trench can be excavated using a small backhoe. For the reference disposal trench described in Appendix E, the excavation work can be performed using large backhoes, draglines, or pan-scrapers. For very large trenches, pan scrapers and draglines become more practical tools for excavation.

The use of emplacement vehicles within disposal trenches introduces several logistics problems including the potential hazard of trench wall collapse, increased labor hours spent in higher radiation fields, and maintaining trafficability within the excavation. The hazard of potential wall collapse is particularly enchanced when long unsupported vertical walls are employed and vehicles operate close to these unsupported walls.

Precipitation management is another consideration. Dewatering of large excavations and maintenance of good drainage in large area excavations can be difficult. If the bottom of the excavation is not properly designed for drainage, the ability to move vehicles within the trench can be diminished. For very large excavations, it is prudent to employ both an active dewatering system (sumps and/or well points) and a full area drain (a layer of granular soil over the bottom of the entire excavation).

Increasing the depth dimension of a disposal trench can have an effect on both land use efficiency and disposal costs. For example, assume that the depth of the reference facility disposal trench is doubled from 8 m to 16 m, while the planar dimensions of the trench (180 m x 30 m), the side slopes (1 horizontal: 4 vertical), and the 1 m backfill thickness between the waste and the original ground surface all remain the same. The additional depth afforded in this example results in a 75 to 80% increase in land use efficiency (from 9.45 ft^3/ft^2 to between 16.5 and 17 ft^3/ft^2). Based upon a total volume of waste disposed of one million m^3, this increased land use efficiency results in a requirement for only 30 disposal trenches as opposed to the base case total of 58 trenches. This also results in a need for only 19.3 ha (45 acres) of land committed for waste disposal as opposed to the 34.7 ha (87 acres) requirement for the reference facility. The cost differential for this example (shown in Table F.4) is estimated to be about $\$3.99/m^3$ ($0.11/ft^3$). (Table F.4 and the other cost analysis tables are presented in Section 5.)

It should be emphasized that this estimate is provided as an illustration and does not consider the operational problems that would be associated with the above example of very deep trench disposal. For instance, the above example does not consider such potential operation problems as ease of trench construction or emplacement of waste. In addition, the above example assumes a very large depth to ground water (greater than 18 m), which may be a very restrictive requirement for humid eastern sites. Another consideration is the assumption that steep (1:4) slopes can be safely employed.

In eastern as well as western states, many substrata are characterized by granular soils that cannot necessarily be successfully excavated at 1:4 slopes. One option would be to greatly reduce the steepness of the site slopes, which could reduce the increased land use benefit of deep burial to an overall land use efficiency of only 40 to 50% higher than that realized by the reference disposal facility. Another more expensive option is trench wall shoring. If trench wall shoring was required in the above example deep disposal trenches, costs would be increased by about $\$24.65/m^3$ ($\$0.75/ft^3$).

Slopes of Excavations

As alluded to above, the existing characteristics of the soil profile at a disposal site can influence the land use efficiency through the need to maintain safe side slopes. Recommended safe side slopes for different soils are outlined in standards published by the Occupational Safety and Health Administration (OSHA). The OSHA standards with respect to excavations (Ref. 1) state that banks more than 5 feet high should be shored, laid back to a stable slope (angle of repose), or that some other equivalent means of protection should be provided where employees may be exposed to moving ground or cave-ins. The recommended excavation slopes for trenches based on soil types are summarized below.

Soil or Ground Type	Slope (H:V)	Angle of Repose
1. Solid rock, shale, or cemented sand and gravels	Vertical	90°
2. Completed angular gravels	1/2:1 (1:2)	63°26'
3. Recommended slope for average soils	1:1	45°
4. Compacted sharp sand	1 1/2:1	33°41'
5. Well-rounded loose sand	2:1	26°34'

The OSHA trenching requirements also state minimum shoring requirements for vertical walled excavations under various ground conditions. In general, gentle slopes result in reduced land use efficiency.

Final Grades

The existing topography of a disposal site can influence the designs employed. For example, construction of disposal trenches on steep slopes can be difficult. Construction equipment is typically difficult to operate on slopes greater than 25%. In addition to construction difficulties and the potential for erosion, operational activities such as waste emplacement can prove to be difficult on steep slopes. Irregular topography can also limit the size of trenches within a tract of disposal facility land.

Hydrogeologic Considerations

The depth of a disposal trench is generally limited by the local depth to ground water. Other hydrogeological factors which impact facility design include depth to bedrock, depth to heterogeneous horizons, and distance to ravines and gullies. These factors can limit the sizes and locations of disposal trenches.

2.2 Control of Potential Intrusion by Humans, Plants, or Animals

This section discusses potential methods which may be used at near-surface disposal facilities to reduce the impacts of potential inadvertent intrusion into disposed waste by humans, plants, or animals. Inadvertent human intrusion into disposed waste can result from such potential human activities as construction of a house or operation of a small garden upon the disposal facility. Intrusion into disposed waste by burrowing animals or deep-rooted plants may also occur and could result in increased exposures to humans through: (1) surfacing radioactive material which could then be dispersed by wind or water, (2) human consumption of contaminated plants and animals, or (3) increasing rainwater percolation into the disposed waste and thereby potentially increasing radionuclide migration through ground water. The immediate impacts of plant and animal intrusion, however, would be considerably less significant than potential direct human intrusion.

Many of the methods described in this section which may be used to reduce or eliminate the impacts of potential intrusion have been either used in the past at existing disposal facilities or require only minor development. Some potential methods, however, such as use of biological barriers to plant or animal intrusion, appear to require additional research and development. In addition, some of the methods discussed in this section have an additional positive effect in that the methods may help reduce potential ground-water migration. Potential operational health and safety considerations are also addressed.

2.2.1 Thicker Trench Covers

One method which may be used to reduce the potential for intrusion (and also minimize intrusion impacts) is simply to increase the thickness of the cover (the trench cap) over the disposal trench. Before analyzing the increased costs that could result from an increased disposal cap thickness, however, it is useful to briefly consider the nature of potential intrusion, and the nature of existing and future disposal facilities. A more extensive discussion is provided in Chapter 4 of this EIS.

The actions of future potential inadvertent intruders are impossible to precisely predict. Nonetheless, it is possible to conservatively postulate two scenarios which could lead to potential significant exposures. One scenario would be the construction of a house on the disposal facility and the second would be persons living in the constructed house and potentially consuming food grown in a small garden located in contaminated soil. In order to postulate that potential significant exposures to intruders can occur under these scenarios, it is necessary to assume that the scenarios involve activities that penetrate the surface of the ground for significant depths. As discussed below, this assumption may be problematical in some cases.

Typically, a near-surface disposal facility would be sited in areas which are flat to gently rolling. The practical reasons for this include ease of construction and promotion of rainwater runoff, while at the same time minimizing erosion. The disposal facility would not be located at a site having significant topographic relief. This implies that major earthmoving activities may not be required for construction of roads, buildings, etc. In many areas of the country, both in eastern and western regions, houses are constructed without basements and with few excavations. Emplacement of water mains, sewage connections and other utilities would, however, typically, involve excavations down to a few meters. Somewhat deeper excavations would result if basements were constructed. A lower range of excavation depth for typical basements for a housing development is believed to be about 3 to 3.5 m (10-11.5 ft) (Ref. 2).

Farming and gardening are surface activities. Plowing, harvesting, and other agricultural activities generally do not involve disturbing the soil for more than a few feet below the ground surface, and many typical root crops have relatively shallow root systems.

In any case, scenarios such as housing construction, or gardening activities at a disposal location require an assumption that persons performing such activities do not know that a potential hazard exists. Although it is difficult to predict with certainty the structural integrity of disposed waste after a few hundred years--particularly wastes such as miscellaneous low-activity trash--objects such as corroded equipment and monolithic blocks of solidified material would probably remain. It is likely, that persons potentially contacting the waste material would recognize that something was out of the ordinary and cease activities. Gardening is not an activity that can profitably be undertaken in a field full of half-buried 55-gallon drums filled with concrete.

At the reference disposal facility, the waste is assumed to be emplaced to a level approximately one meter below the top of the trench. This one meter space is filled with overburden, and a cap is then emplaced which is also assumed to be one meter thick. This results in approximately two meters (6.6 ft) of earth between the top of the waste and the surface of the ground. This thickness of cover would probably preclude contact of the waste through most potential agricultural activities, but may still allow partial contact through such activities as construction of a basement.

An additional 3 meters of overburden would raise the distance between the waste and the ground surface to about 5 meters (16.4 ft). The thickness would place the top of the disposed waste about 1.5-2 meters (5-6.6 ft) below the lower level that typical basements would be expected to be constructed. An earthen thickness of 3 to 5 meters would also be expected to place the waste below typical burrowing depths of many burrowing insects and animals, as well as below the root depths of many plant species--particularly many food crops.

At existing disposal facilities, disposal trenches are excavated, filled with waste, covered over with previously excavated soils, and capped. There is usually considerable excess dirt from trench excavation and this dirt is generally applied as additional overburden over the trench cap. Existing disposal facilities often have as much as 8 to 12 feet (2.4 to 3.7 m) of earth separating the top of the disposed waste and the surface of the earth. An upper bound estimate of the costs of increasing the disposal cell cover thickness can be made by using standard construction cost estimation guides (Ref. 3). At a rate of \$0.75/yd^3 (\$0.98/m^3) to excavate, haul (assume a 1,500 ft haul distance), and spread earth using scrapers, increasing the earthen thickness over the disposal cells by 3 meters would cost an approximate additional \$1.59/m^3 (\$0.05/ft^3) (See Table F.5).

In a similar vein, an increased distance between the ground surface and the top of the disposed waste could be achieved by increasing the thickness of earthen material between the top of the waste and the top of the trench. This is assumed to be equal to one meter at the reference disposal facility, which results in a thickness of earthen material between the waste and the top of the trench cap equal to about 2 meters. If only the bottom 4 m out of the 8 m excavation were used for waste disposal, the thickness of earthen material between the waste and the top of the trench cap would be increased to 5 m (16.4 ft). The reduction in potential intruder impacts would be equivalent to the case described above regarding increased overburden thickness, but would be brought about through decreased land use efficiency. If at the reference disposal facility only the bottom 4 m (instead of the bottom 7 m) of all disposal trenches were used for waste disposal, then the land use efficiency would be dropped from about 2.9 m^3/m^2 to approximately 1.6 m^3/m^2. The land area committed to waste disposal would be raised from about 87 acres to about 157 acres, and the number of disposal trenches constructed raised from 58 to 105. Due to the additional amount of trench construction, filling, grading, seeding, and other groundskeeping activities that would be performed, costs would be proportionately raised (by about \$4.7/m^3 or \$0.13/ft^3) (See Table F.6).

At existing disposal facilities, the thickness of earthen material emplaced between the top of the waste and the top of the trench typically ranges from about one to eight feet. For example, at the Barnwell, SC disposal facility, this distance for most disposal trenches typically ranges from about one to three feet. (After backfilling, installing the cap, and covering with overburden, however, the distance between the top of the waste to the ground surface usually ranges from 2 to 3 meters.) In addition, slit trenches have been used in the past at the Barnwell facility for disposal of wastes having high surface activity levels. Typically, a fill thickness of 10-12 feet was used for shielding purposes (Ref. 4). These trenches, however, involved disposal of only a small volume of waste.

At the commercial disposal facility located in the Hanford Reservation near Richland, Washington, license conditions require a minimum earth thickness of eight feet between the top of the waste and the original ground surface (Ref. 5). The site is located in an extremely arid area (about 6 inches of rain per year), and the depth to the ground-water table is on the order of 100 m (Ref. 6). Therefore, disposal trenches can be dug to greater depths than at the reference facility located in the humid eastern U.S. (Typically, trenches are excavated at the Richland commercial disposal facility to depths of about 12 meters, as opposed to the assumed 8 m at the reference facility, resulting in no significant loss in land use efficiency (Ref. 7).

2.2.2 Disposal of Wastes Having High Radiation Levels

It is expected that the majority of the waste streams that would require disposal by methods that provide protection against inadvertent intrusion would also be characterized by high surface radiation levels. Other wastes having high surface radiation levels may be dominated by short-lived isotopes, and therefore may not be of significant concern to a potential future inadvertent intruder. However, the temporary high radiation levels associated with such wastes would still require additional care during waste handling and disposal operations. It is useful, therefore, to consider a number of potential waste disposal concepts which may offer increased protection against the actions of a potential inadvertent intruder, while at the same time offering increased worker radiation protection during waste handling and disposal operations.

Typically, only a small fraction (about 10%) of the packages received at commercial radioactive waste disposal facilities would be characterized by elevated exposure rates (e.g., greater than about 5 R/hr). These wastes pose some restrictions on operations at disposal facilities. At the present time, most high exposure rate ("hot") waste is dealt with on a case-by-case basis. For example, optimal locations for shielding in trenches are often reserved for high exposure rate waste packages. Optimal locations in trenches can include corner locations and positions between waste packages having low activity levels. Additionally, rapid partial backfilling of high exposure rate packages may be employed to reduce radiation levels to acceptable working levels.

Special "hot" waste disposal cells have been employed from time to time at some of the commercial disposal facilities, as well as at some of the U.S. Department of Energy radioactive waste disposal facilities--e.g., Oak Ridge National Laboratory, (Ref. 8) the Hanford Reservation, (Ref. 9) and Los Alamos Scientific Laboratory) (Ref. 10). The types of disposal cells that have been employed for disposal of high-exposure-rate waste packages have included slit trenches, caissons, reinforced concrete culvert pipes, auger holes, and toner tubes (a specific type of caisson with a basket funnel for introducing waste packages).

The following subsections discuss four potential disposal methods which can be used to reduce or eliminate potential inadvertent intruder impacts while at the same time reduce potential worker exposures during site operations. These methods include layered disposal, slit trenches, caisson disposal, and walled trenches. Caissons and walled trenches are two examples of possible use of "engineered structures" for waste disposal. Following these subsections are two sections which investigate additional methods by which potential inadvertent intruder exposures may be reduced or eliminated. These include grouting interstitial voids between disposed waste packages with cement grout and installation of engineered human intruder barriers.

2.2.2.1 Layered Waste Disposal

Protection against inadvertent intrusion may be accomplished by layering of the waste according to the relative hazard of the waste. The concept of trench layering involves placement of wastes having a higher potential hazard along the bottom of the trench with wastes having a lower potential hazard emplaced on top. Typically, higher potential hazard waste would include waste packages characterized by high surface radiation levels or wastes that could pose a significant airborne hazard if disturbed by excavation.

For illustrative purposes, the example case of layered waste disposal employs the same trenches described in the reference disposal facility (Appendix E). In the reference facility trench, only the bottom 7 m out of the 8 m excavated is used for disposal of waste. In layered waste disposal, the bottom 2 m of the excavation is assumed to be reserved for disposal of higher potential hazard waste material. Any remaining space in the bottom 2 m is used for disposal of lower activity waste. The 5 m of space available above the bottom 2 meters is also used for disposal of lower potential hazard waste material (see Figure F.1). Thus, the inadvertent intruder would have to dig through 2 m of backfill and 5 m of lower hazard waste before encountering waste that could result in a significant potential exposure. Excavation work that uncovered boxes and drums of low activity waste would probably discourage further excavation long before the more hazardous material was reached. Layered waste disposal would also help to reduce personnel exposures during disposal operations by providing additional shielding for wastes having high gamma radiation levels.

The option of layered waste disposal would not appreciably alter facility design, operations or labor requirements. However, there would have to be an adequate mix of lower hazard to higher hazard waste on hand to allow for successful implementation of the option (i.e., a lower hazard waste to higher hazard waste volume ratio of about 2.5 to 1 or greater). Maintaining an input of waste at this ratio would require either careful scheduling of input from waste generators, and/or implementing greater storage capability at the site. For example, if higher activity waste were to be received at the site at a rate equivalent to that of the lower activity waste, a fraction of it would be buried as it was received, while the remainder would be stored for future disposal (when sufficient lower hazard waste became available). It would also be necessary to have the capability of transporting the waste from the site waste storage area. Therefore, operational changes at the disposal facility could involve temporary storage of waste, additional coordination of waste receipt and emplacement, and transport of stored waste from the storage area to the disposal trench. Significant cost differences are estimated to include construction of an inexpensive moderate-sized waste storage facility (e.g., an open-sided roofed structure intended to provide some weather protection for the stored wastes, and perhaps a storage pad with tarpolins for large packages), and hiring of some additional personnel. The estimated cost differential for this option (shown in Table F.7) is about \$37.73 per m^3 for waste requiring layered disposal (\$1.07/ft^3). No additional land would be committed to waste disposal.

2.2.2.2 Slit Trench Disposal

A slit trench typically has a length dimension which is more than 5 times the width dimension (the width dimension is generally less than 5 meters). The depth of slit trenches used in the past at disposal facilities (e.g., at Oak Ridge National Laboratory (Ref. 8) and the Barnwell, S. C. commercial disposal facility (Ref. 11)) have been generally equivalent to the excavation depths of the larger disposal trenches employed at the facilities. For the assessment performed in this appendix, the assumed dimensions of vertical walled slit trenches are assumed to be 20 m in length, 3 m in width and 8 m in depth. The minimum spacing employed between slit trenches is assumed to be 2 m. The assumed disposal efficiency is 50%, which means that only 50% of the total available void space is eventually occupied by waste packages.

For the cost analysis provided in Section 5 of this appendix (see Table F.8), it is assumed that 10% of the waste volume received at the facility requires

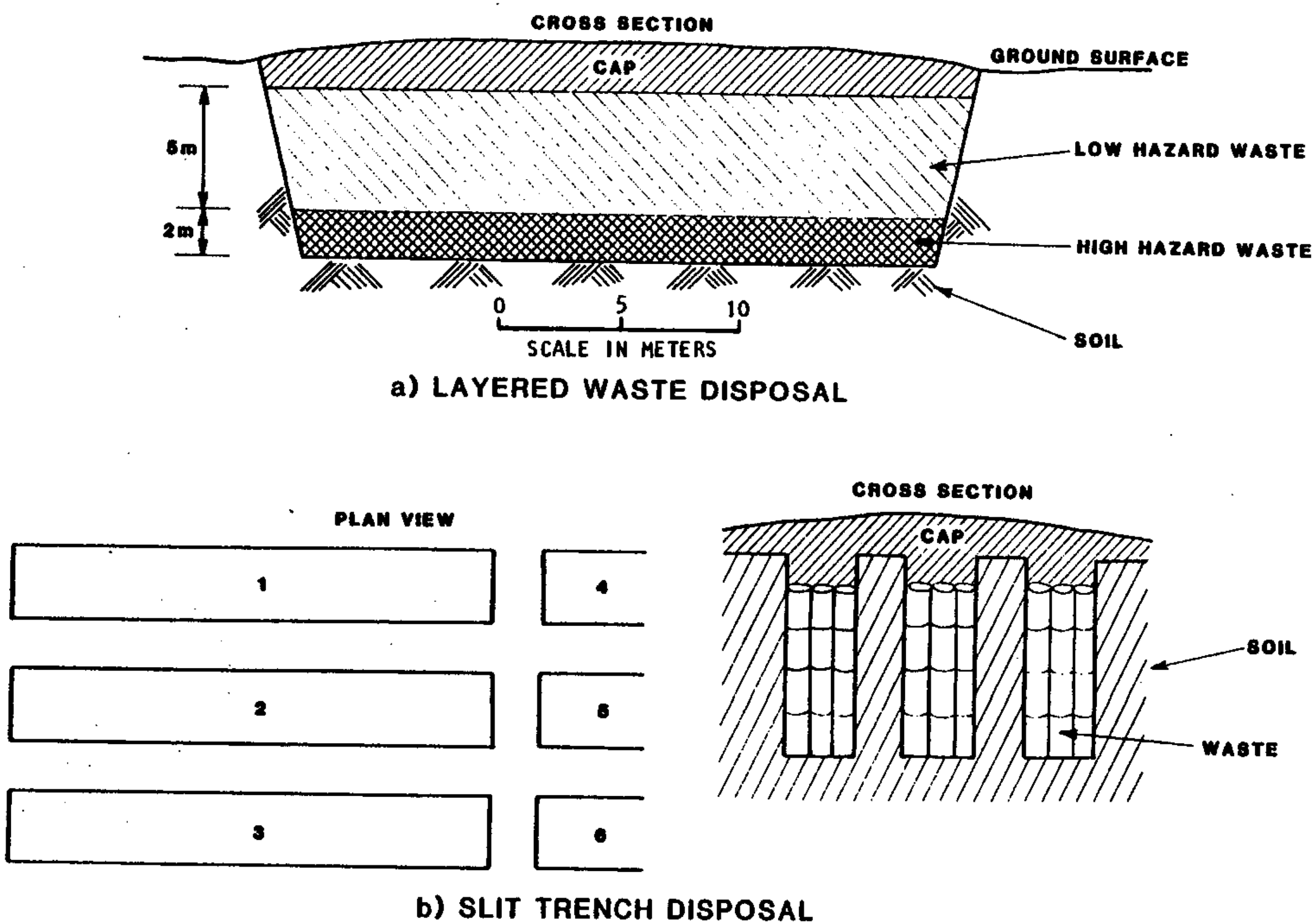


Figure F.1 Layered Waste and Slit Trench Disposal

disposal using slit trenches. The assumed slit trench dimensions and spacing imply that the land use efficiency of slit trench disposal is approximately half the efficiency of the reference trenches (180 m x 30 m x 8 m) described in Appendix E (or about 4.7 ft^3/ft^2). The unit cost differential between the base case unit disposal cost for the "hot" waste requiring slit trench disposal, shown in Table F.8, is \$91.49 per m^3 of waste disposed into slit trenches (\$2.59/ft^3).

This cost is calculated assuming that no shoring is used during slit trench construction and waste emplacement, which raises difficulties regarding emplacement of standpipes and French drains. That is, for the reference disposal facility, after initial construction of the disposal facility trenches, some additional construction work inside the trenches is needed to smooth the disposal trench floor and to provide a gentle slope to the gravel-filled French drain which runs along one side of the trench. The French drain also slopes toward one end of the trench where a gravel-filled sump is excavated. Standpipes are then placed into the sump and at other locations in the French drain. Performing such activities within a deep, narrow slit trench, however, raises operational safety questions. Since a smooth trench bottom cannot be assumed, the usefulness of standpipes and French drains were considered questionable and were therefore assumed not to be installed in the slit trenches. If shoring were used--either to allow construction work inside the slit trenches or to maintain side walls during waste emplacement--then unit costs for slit trench operations would be considerably higher.

The slit trench option results in an additional 1.6 ha (4 acres) committed to waste disposal. The overall land use efficiency for this option is estimated to be 8.75 ft^3/ft^2 (mixture of regular and slit trenches). The major anticipated benefit of employing this option is a reduction in the occupational exposures received by the waste emplacement labor force at the disposal facility. It is estimated that the use of slit trenches can possibly reduce occupational exposures by between 10 and 20%. Use of slit trenches for high activity wastes would be expected to reduce potential intruder exposures by a factor of about two. Some drawbacks to the use of slit trenches include the added expense and moderate slope failure hazards existing for vertical walled trenches. Additional drawbacks include the difficulty in installation of reliable monitoring devices within the trenches. The restricted width dimensions of slit trenches may preclude the burial of very large waste packages.

2.2.2.3 Caisson Disposal

To represent the estimated costs and anticipated benefits of use of caissons, tubes, or reinforced concrete pipes for disposal of high activity waste, an example case employing reinforced concrete pipes is evaluated. In the illustration provided here, each "hot" waste disposal cell is assumed to consist of a 30 in (0.6 m) inside diameter reinforced concrete culvert pipe which is 24 ft (7.3 m) in length. These culvert pipes are inserted vertically into a slit trench which is 15 m (50 ft) in length, 1.5 m (5 ft) in width and 8 m (26 ft) in depth. After waste emplacement, the culvert pipes are assumed to be capped with a 0.6 m (2 ft) thick layer of concrete. Earthen overburden is then applied, graded for drainage, and seeded. Void spaces between the caissons are assumed to be backfilled with earth (see Figure F.2).

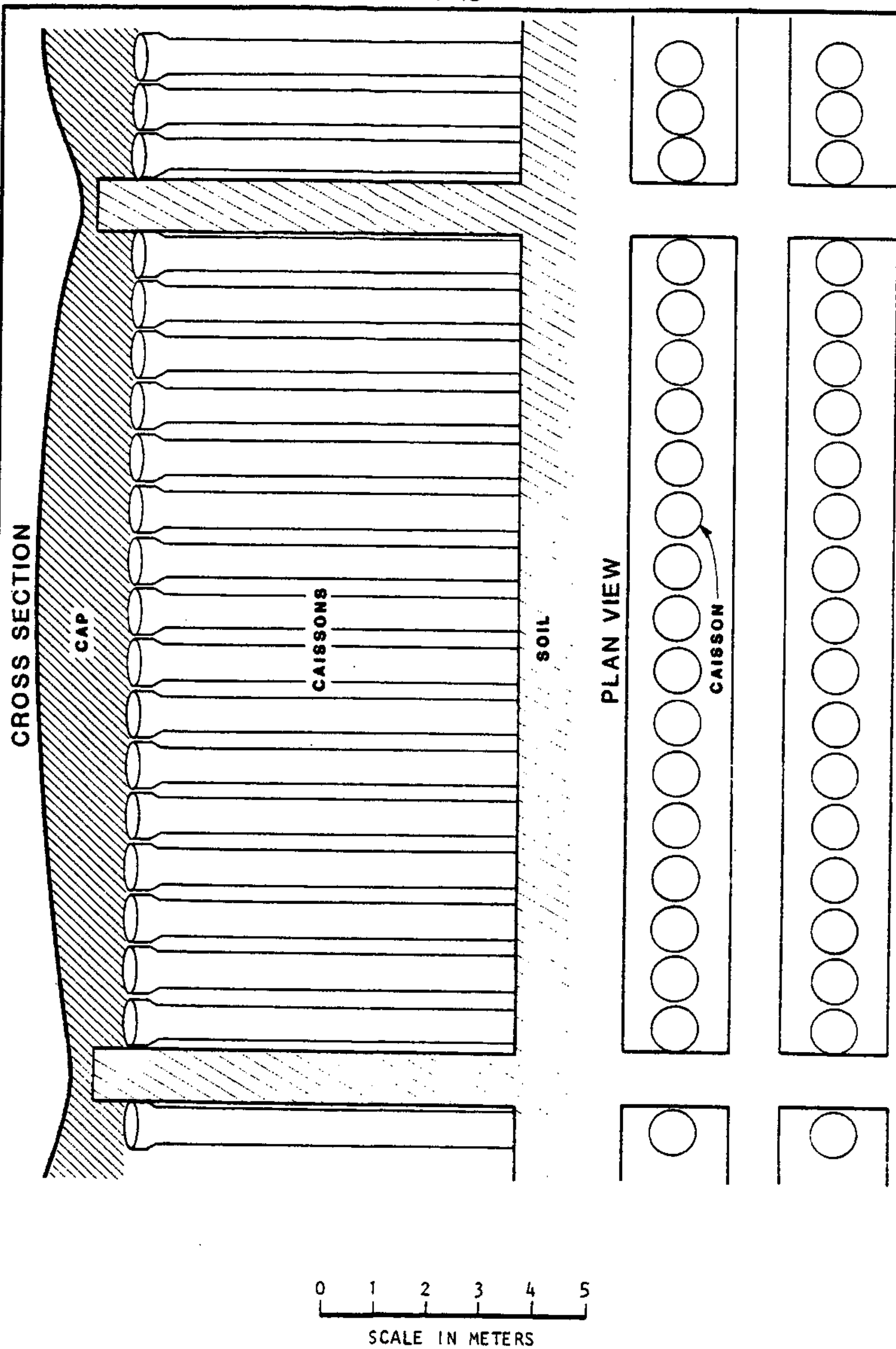


Figure F.2 Caisson Trench Disposal

Each slit trench can accommodate 16 of the reinforced concrete culvert pipes, which can accommodate either 55- or 83-gallon drums. Larger diameter pipes could be used for larger waste packages. As a result of the lower potential for slope failure resulting from the lateral structural support provided by the culvert pipes and the shielding provided by the concrete, the inter-trench spacing can be reduced. Therefore, each slit trench is assumed to be separated from adjacent trenches by a minimum of 1 m (3.3 ft). This results in an overall land use efficiency which is about 60 to 65% of the efficiency attained for the reference trenches (180 m x 30 m x 8 m) described in Appendix E. The reduction in occupational exposures provided by this option is probably similar to that estimated for the slit trench case described earlier (10 to 20%).

As an illustration, costs are estimated for an example in which 10% of the waste received at the disposal facility is disposed using caisson trenches. The estimated cost differential above the reference case for this example (shown in Table F.9) is \$216.45 per m^3 of waste disposed into the caisson trenches (\$6.13/ft^3). Again, these costs were calculated assuming that no shoring is used to construct the caisson trenches and consequently no gravel drains or monitoring standpipes are installed. Similarly to the previous case, if such shoring were required, unit differential costs would be considerably higher.

2.2.2.4 Concrete Walled Trench Disposal

A third type of "hot waste" disposal cell which has been employed for selected wastes in foreign countres (e.g., Chalk River, Canada) (Ref. 12) is a walled trench. For illustrative purposes, the concrete walled trench is assumed to be constructed of reinforced concrete and having 0.3 m (1 ft) thick walls and floor. The depth of the trench from the top of the trench walls to the floor of the trench is assumed to be 8.3 m, while the inside planar dimensions are assumed to be 12 m by 3 m. A 0.3 m gravel base is then assumed to be emplaced in the bottom of the trench prior to waste emplacement. A monitoring standpipe is also emplaced into one corner of the trench. The waste is then assumed to be stacked into the trench to a height of 7 m. Interstitial voids may be filled with earth or, for increased stability and intruder protection, by a cement grout. Filled trenches are then covered by a one meter thick concrete cap followed by a layer of overburden graded for drainage. The walled trenches described here are capable of handling 55- and 83-gallon drums, as well as steel liners up to 1.8 m (6 ft) in diameter. The dimensions of the walled trenches can also be increased to be able to handle larger sized waste packages, at a decrease in radiation shielding to facility workers.

The spacing between walled trenches is assumed to be a minimum of 3 m as a result of the requirements for concrete forming work. Due to the larger spacing required for this type of disposal cell and the volume lost by the wall displacement, the land use efficiency is calculated to be less than 25% of that for the reference trench. The anticipated reduction in occupational exposure for waste emplacement workers should be roughly equivalent to that estimated for the other "hot" waste disposal options (about 10 to 20%).

Differential costs are estimated for (1) an example in which 10% of the waste volume delivered to the disposal facility is assumed to be disposed in concrete

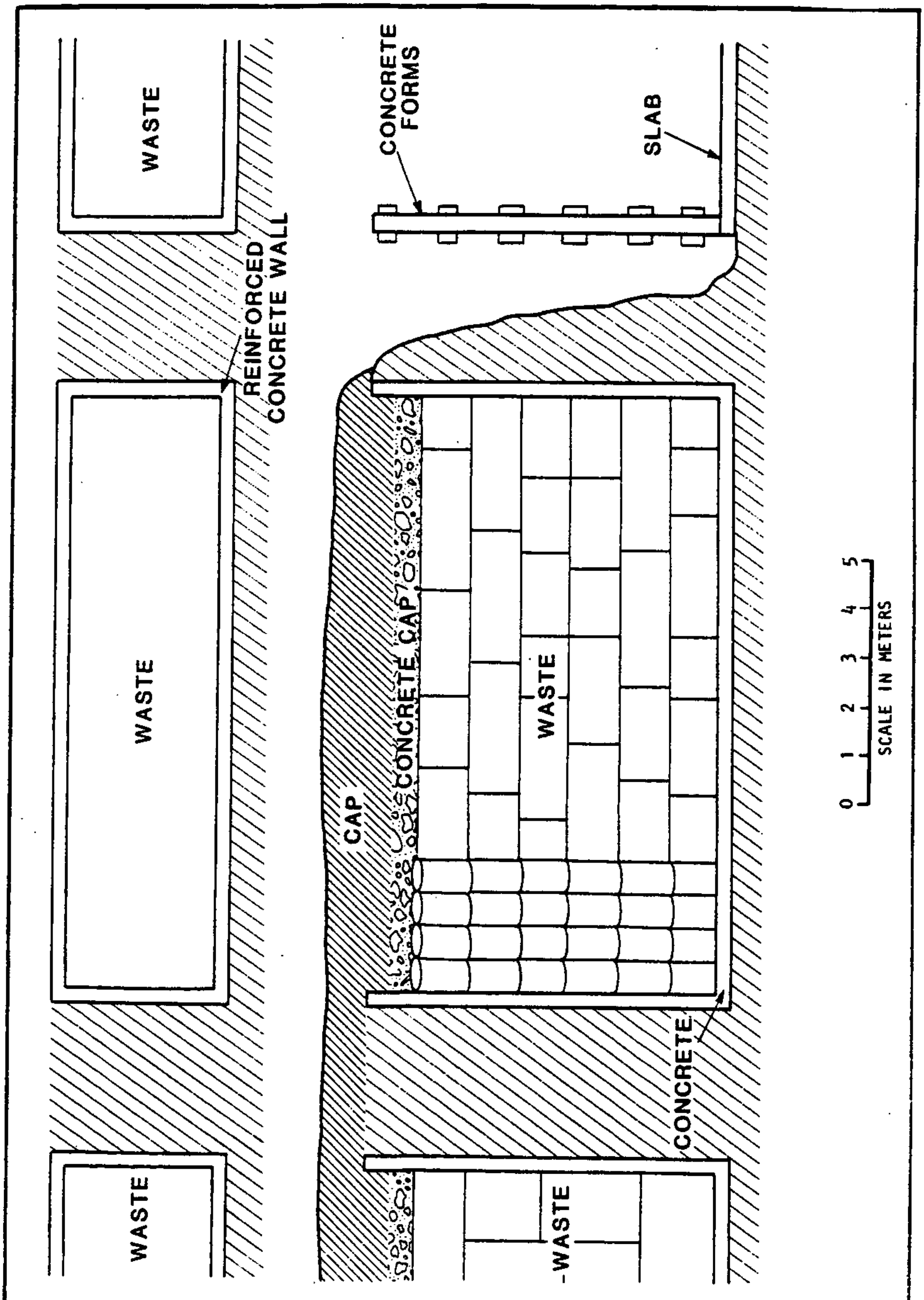


Figure F.3 Concrete Walled Trench

walled trenches, and (2) an example in which 100% of the waste is disposed in concrete walled trenches. These differential costs are presented in Tables F.10 and F.11, and are $256/m^3$ ($7.25/ft^3$) for the former example and $161/m^3$ (84.56/ft^3) for the latter example. The effects of economics of scale are apparent. Additional land use for the two examples are, respectively, 4.1 acres and 39.5 acres. Costs (for 10% of waste disposed) are seen to be higher than either slit trenches on caisson trenches. The additional land use, however, is less than these two cases.

Based on the relatively higher cost, this option may not be warranted to achieve lower occupational doses. On the other hand, this option affords a greater degree of protection for the inadvertent intruder.

2.2.3 Grouting

Another available method which could be used to reduce intruder impacts would be to fill void spaces between waste packages with a cement grout. The grout would greatly increase the difficulty of excavating into the disposed waste. The cement fill would also provide greater radiation shielding than ordinary dirt backfill. In addition, since the grout would also reduce trench cover subsidence and subsequent infiltration of rainwater into the disposed waste, decomposition of the disposed waste would be reduced. This reduces the potential for airborne dispersion and increases the likelihood that an intruder would recognize that something was out of the ordinary and investigate.

For illustrative purposes, the waste packages are assumed to be stacked into the reference disposal trenches prior to grouting. As discussed in Section 2.3.3.1, this is more costly than random emplacement and increases occupational exposures. The relative cost of cement grouting is high, however, and the less void volume requiring filling, the lower the overall costs will be.

In this example, the waste is emplaced in layers. After each layer is completed, tremie pipes are lowered to the base of the trench through void spaces between the waste packages at perhaps 6 to 8 separate locations. The grout is pumped through the tremie pipes until the grout level reaches the top of the first waste layer. The pumping activities generally would be carried out in stages (grouting each layer in areal sections). After the first waste layer is grouted, additional waste emplacement could proceed. Each layer of waste would be similarly grouted.

The grouting operation for each layer would probably consume at least one to two weeks of time. In order that waste disposal operations not be halted during grouting, it would be necessary to operate with two or more trenches open concurrently. The labor force would also have to be augmented. Additional supplies and equipment would include grouting equipment (pumps, hose, and tremie pipes), and cement. An increase in the storage area would also be needed for warehousing the cement prior to use.

The estimated differential cost for this disposal option, excluding the cost for waste stacking, is about $38 per m^3 of disposed waste ($1.08/$ft^3$), or about $115 per m^3 of grout (see Table F.12).

A less expensive alternative could involve use of controlled density fill in place of the cement grout. In this example, the controlled density fill is assumed to be a commercially available lower strength concrete. The material is emplaced in layers using tremie pipes in a similar manner as the grout fill and is identical to the grouting case with respect to operational, equipment, and manpower requirements. The principal difference is cost because the low density concrete is considerably less expensive than the cement grout. The estimated differential cost for the controlled density fill (excluding the cost for waste stacking) is about \$24 per m^3 of disposed waste (\$0.70/ft^3) or about \$74 per m^3 of grout. Other than cost, the only appreciable difference in the final trench status is the overall strength of the fill. Controlled density fill will provide additional support to the trench cap but is more capable of being excavated. Therefore, the controlled density fill provides slightly less intruder protection. The benefits to trench cap integrity and leach resistance are assumed to be equivalent to that for grout cement.

2.2.4 Bio-barriers

As discussed above, potential intrusion of burrowing animals and deep-rooted plants into disposed waste at a near-surface disposal facility can potentially impact humans in three ways.

- o Radionuclides may be brought to the surface where they may be dispersed by wind and water.
- o Contamination on or within plants and animals may be potentially eaten by humans.
- o Plant and animal intrusion can create pathways in a disposal trench cover for increased percolation of rainwater into the disposal trench, thus potentially increasing ground-water migration.

Some typical burrowing depths of certain animals are provided below (Ref. 13).

Species	Maximum Typical Burrow and Tunnel Depth
Harvester Ant	3.0 m
Moles	1.2 m
Pocket Gopher	0.6 m
Pocket Mouse	1.6 m
Deer Mouse	0.6 m
Field Mouse	0.6 m
Earthworms	0.5 m

Root depths of plants can, depending upon the species, range from fairly shallow depths to very deep depths. Some plants native to arid regions, for example, have root depths that can range up to 100 feet.

Occasional cases of plant and animal intrusion have been documented at disposal facilities operated by the Department of Energy (DOE). For example, at the Hanford Reservation, cribs have been extensively used in the past for disposal of liquid waste, and are still occasionally used at the present time. (A crib is a shallow disposal trench, occasionally gravel-lined, into which liquids are piped and allowed to percolate into the sandy soils.) Burrowing animals such as jackrabbits have, on occasion, burrowed into the cribs in an effort to obtain salts deposited by the percolating liquids. Radioactive salts thus consumed were then dispersed by the burrowing animals and their predators. On other occasions at the Hanford Reservation, swallows have been known to obtain radioactive mud from settling basins for use in constructing nests (Ref. 14).

Other incidents have been noted at the Hanford Resrvation in which plants growing over disposal trenches and cribs have accumulated fission products and transuranic elements in shoot tissues (Ref. 15).

At the Oak Ridge National Laboratory (ORNL), a tree has been reported to have been removed from the disposal area after it was noticed to have accumulated radiocontaminants (Ref. 16). Mud-dauber wasps have also been observed at this facility to have built nests from contaminated mud obtained from waste seeps (Ref. 14).

Uptake and dispersion of radiocontaminants by plants and animals has not been reported at commercial disposal facilities. However, at the Sheffield disposal facility, a small animal burrow was reported in a study by Heim and Machalinski. The authors pointed out that the burrow, which was about 20 inches in depth, was a potential concentrated source of rainwater infiltration (Ref. 17).

Actual potential impacts of plant and animal intrusion into disposal wastes are site-specific and are, furthermore, difficult to predict. Some of the factors which greatly influence potential impacts include:

- The climate of the disposal site.
- The varieties of plants and animals indigenous to the disposal site.
- The characteristics of the disposal operations.
- The characteristics of the disposed wastes (e.g., higher potential impacts would be expected from wastes having higher radionuclide contents, and/or wastes with higher potential for leaching or dispersion).

The impacts that have resulted from documented cases of plant and animal intrusion have not been cause for a significant public health and safety problem. Nontheless, the fact that plant and animal intrusion has occurred in the past makes it worth considering during development of regulations for near-surface disposal of waste. It would probably be most advantageous to consider ways in which the occurrence of plant and animal intrusion can be minimized or eliminated. This is believed to be probably of most significance in helping to reduce potential migration of ground water to levels as low as reasonably achievable.

Many of the potential methods which can be used to minimize plant and animal intrusion or to reduce the impacts of such potential intrusion are similar or identical to those which are useful against potential human intrusion. For example, the potential for (and resulting impacts from) plant and animal intrusion can be minimized by:

- o Increasing the thickness of earthen fill between the top of the disposed waste and the facility surface.
- o Placing higher activity material farther below the surface (layering the waste).
- o Reducing the potential for leaching and dispersion of waste forms, particularly higher activity wastes.

Barriers against intrusion may also be used. One barrier which has been used with success (Ref. 14) against intrusion by burrowing animals is emplacement of a hard surface such as rip-rap, cobbles, or asphalt over the top of disposal trenches. The hard surface greatly discourages or eliminates burrowing mammals and has the added benefit of controlling potential wind and water erosion. Coatings of cobbles over filled disposal trenches are currently being routinely used at the Hanford Reservation, both at the disposal areas operated by DOE and the commercial disposal facility located within the reservation (Refs. 5 and 9).

Over the past several years, work on development of biological barriers effective against deep-rooted plants and burrowing insects in addition to burrowing mammals has been performed by Cline, et al., (Refs. 15 and 18). The study was limited to an arid area (annual precipitation of about 6.25 in) and involved use of a large test trench in addition to 16 small lysimeters. The barrier consisted of a .6 to 1.2 m layer of cobble stones (2.54 to 5.1 cm in diameter) over which was emplaced a .32 to 1.05 m layer of soil. Between the cobbles and the soil was emplaced different additional barriers: (a) nothing, (b) a 25 mm layer of small (0.3 to 0.6 cm in diameter) stones, (c) a 25 mm layer of small stones covered by 175 cm of 10% asphalt emulsion in water, and (d) 25 mm layer of stones covered by the asphalt emulsion mixed with root toxin.

Use of the cobbles alone appeared to be effective against intrusion by harvester ants and pocket mice, but ineffective against intrusion by russian thistle (tumbleweed) roots. Russian thistles are common in the western United States and are aggressive water seekers. Fine soil particles sifted down into the cobbles, creating a path followed by the roots. The layer of small stones prevented soil from sifting down into the cobbles and slowed down, but did not prevent, penetration of russian thistle roots through the cobbles. (It was theorized by the authors of the study that air spaces between the cobbles helped to slow root growth.) In the study, the asphalt layer and the asphalt/root toxin layers were 100% effective in preventing the penetration of roots through the cobbles. In addition to providing a physical barrier to plant roots, the asphalt layer would be expected to reduce percolation of water into the cobbles, thus creating a dessicated zone beneath the asphalt layer which plant roots would be less likely to enter. The root toxin killed plants whose roots contacted the toxin.

It is possible that a layer of herbicide placed at an appropriate distance below the ground surface over a disposal trench could be used to prevent intrusion of deep-rooted plants. Deep-rooted plants would be killed when their roots contacted the toxin, while shallow-rooted plants would survive to provide a ground cover. Herbicides are also available that are nontoxic to the plant but inhibit root growth.

A disadvantage is that herbicides tend to degrade in soils, sometimes fairly rapidly. Measures would need to be developed to ensure the effectiveness of the herbicide over extended time periods--i.e., up to 100 years. It has been suggested that controlled release of herbicides could be accomplished by encapsulating the herbicides within a polymer membrane. The membrane would act both as a reservoir for storage of a herbicide and as a sustained and controlled delivery vehicle to release herbicide to the soil (Ref. 19). Controlled release of chemicals through membranes has been frequently used in the past for such applications as home pesticide dispensers and pet flea collars (Ref. 20) and is under study for use in applications such as interuterine birth control devices (Ref. 21).

To summarize, the use of cobbles or asphalt layers would appear to be straight-forward in application against intrusion by burrowing mammals. Additional work is required, however, to develop effective biological barriers against intrusion by plant roots, particularly in humid environments. In any case, construction of elaborate biological barriers could prove to be an expensive hinderance as long as trench subsidence problems were in evidence at a disposal facility. Subsidence problems would tend to crack rigid surfaces such as asphalt layers or concrete, thus reducing or eliminating their effectiveness. Repairs or restabilization activities would also tend to be more difficult and more expensive.

2.2.5 Engineered Human Intrusion Barriers

Just as it may be feasible to construct biological barriers against intrusion into disposed waste by animals and plant roots, it may also be feasible to construct engineered barriers against intrusion into disposed waste by humans. The barrier function could be combined with other functions such as control of potential erosion and eliminating potential intrusion by plants and animals.

An inadvertent future intruder could be a small construction company digging excavations for foundations for a small housing development or a gardener tilling the land. An effective intruder barrier would therefore include some component which would discourage the intruder from digging into the buried waste. That is, once a barrier component is encountered, the intruder would then either be permanently discouraged or would seek more information about the land being worked upon before proceeding with work again. This component may be a large thickness of cobbles, a layer of boulders, a concrete mat, or any equivalent means of deterring excavation.

In general, an intruder barrier constitutes a thick trench cover and can therefore reduce the possibility of erosion resulting in uncovering of buried waste. The protection against significant erosional events provided by the intruder barrier should be capable of lasting for several hundred years.

A third important function of an intruder barrier is to prevent transfer of radiocontaminants into the food chain. The principal concerns of food chain uptake include burrowing animals (e.g., rabbits, mice, ants) and deep-rooted plants.

For illustrative purposes, the conceptual intruder barrier which will be evaluated consists of multiple layers of sand, clay, gravel, cobbles, and boulders. Viewing the intruder barrier from the final ground surface down to the buried waste (as an intruder would encounter it, see Figure F.4), the barrier consists of 0.5 m (1.6 ft) of topsoil with shallow rooted vegetation, 0.75 m (2.4 ft) of sand, 0.25 m (0.8 ft) clayey soil layer, 0.5 m (1.6 ft) of sand, 0.1 m (0.33 ft) of asphaltic concrete, 0.9 m (3 ft) of gravel, 1 m (3.3 ft) of cobbles (7.5 to 15 cm diameter), 1.0 m (3.3 ft) of boulders and 0.5 m (1.6 ft) of sand. The total thickness of this intruder barrier is 5.5 m (18 ft). This intruder barrier is installed on top of the existing 2 m (6.6 ft) of backfill and trench cover.

The resulting distance between any potential inadvertent intruder and the buried waste is 7.5 m (25 ft). This represents a depth far in excess of most small construction activities (e.g., housing developments) and farming activities. The principal potential threats to intrusion for depths greater than 7.5 m are well drilling and deep foundation construction. The 2 m (6.6 ft) of cobbles and boulders coupled with the 0.1 m (0.33 ft) of asphaltic concrete should help to alert any drilling or heavy construction labor forces to the prospect that they should not be working at that location. The required costs to remove the asphaltic concrete, cobbles, gravel, and boulders should also aid in discouraging the attempted construction activities.

Of the near-surface design options, the construction of an intruder barrier represents one of the larger cost additions. For example, the estimated cost differential for a disposal facility with an intruder barrier such as the one described above installed over all of the reference disposal trenches is about $59/m^3 ($1.68/ft^3). (See Table F.13.)

As discussed earlier in Section 2.2.4 regarding biological barriers, installation of an engineered intruder barrier such as the one described above would tend to become an extremely expensive enterprise unless subsidence of the disposal trench cap had been eliminated. The whole point of an engineered intruder barrier is that once it is installed, it is difficult to remove. Any repairs or trench restabilization work required after barrier installation would be both expensive and difficult.

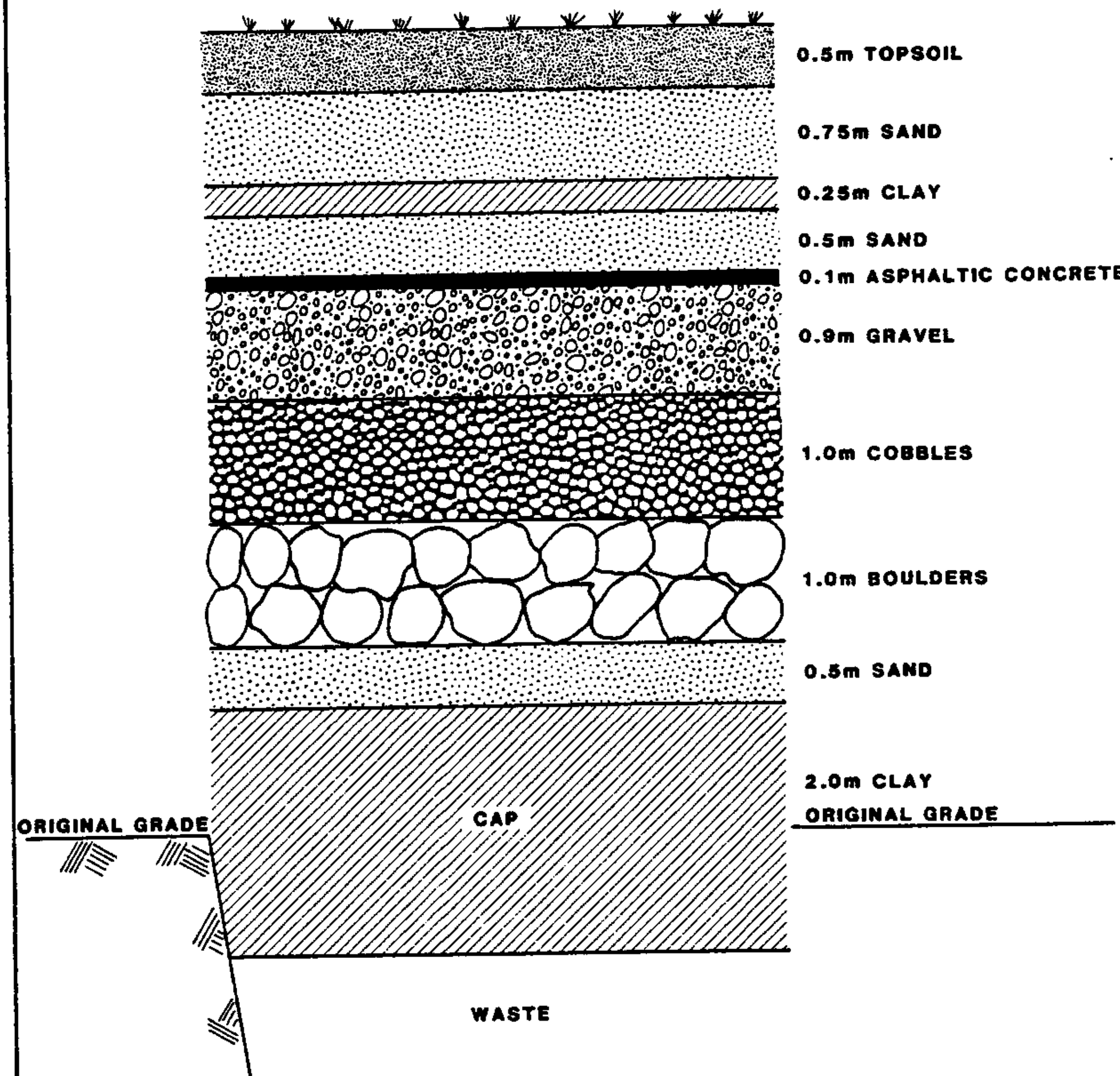


Figure F.4 Engineered Intruder Barrier

2.3 Control of Potential Long-Term Environmental Releases

2.3.1 Improved Monitoring

In Appendix E, an environmental monitoring program is described for the reference disposal facility. As part of this environmental monitoring program, samples for analysis are obtained from monitoring wells, air samplers, and thermoluminescent dosimeters, as well as from soil and vegetation. The monitoring system is intended to provide information on the potential movement of radionuclides away from active disposal trench areas, completed trenches, and other areas where radioactive materials are handled. In the long run, the monitoring system supplies information regarding performance of the site with respect to protection of ground water and protection of the health and safety of the public. The system should therefore be designed so that performance can be evaluated with confidence. Confidence in the monitoring system is provided when it can be demonstrated analytically that no significant contamination can leave the site without being detected.

This EIS is concerned with determining appropriate overall performance objectives and technical criteria for LLW disposal and, therefore, operational details such as recommended methods of installing monitoring wells or the optimum locations for monitoring wells are beyond its scope. Such information can be obtained elsewhere (e.g., Refs. 22, 23). It is useful, however, to briefly consider the approximate level of costs that would be associated with an improved monitoring system. Areas considered in this appendix in which environmental monitoring can be improved relative to the reference facility include increasing the reliability of the ground-water and surface water monitoring, and airborne particulate monitoring.

For an improved ground-water monitoring system, the site operator is assumed to contract with a consulting hydrologist to help design the system. The hydrologist would collect enough data to ascertain the gradient of the water table, the average flow rate, and the dispersion characteristics of the subsurface media. The confidence level of a ground-water monitoring system is a direct function of the distance between the wells and the potential sources of contamination (trenches), and the frequency of sampling. Statistical methods to determine the optimal well locations, spacing, and sampling frequency have been described in the literature (Ref. 24).

For illustrative purposes, the improved ground-water monitoring system includes a total of 20 perimeter wells along the restricted area fence (as compared to 10 for the reference facility). Each of these perimeter wells extend several feet into the saturated zone (minimum depth of 19 m). The perimeter wells are sampled quarterly, as opposed to semiannually as in the reference facility. The number of monitoring wells within the trench areas is raised from 15 to 30, and these wells are also sampled on a quarterly basis. The locations of these wells are selected based on the analysis performed by the consulting hydrologist.

In the reference facility monitoring system, surface runoff is not routinely monitored. The improved monitoring system employs a flow activated automatic runoff monitoring system used in conjunction with a discharge channel located at the northeast corner of the site. Flow composite samples are collected on a weekly basis and sent to an offsite laboratory for radiochemical analysis. This monitoring system is operated during the 20-year operational period.

The final component of the improved monitoring system is an expansion of airborne particulate monitoring. The three-location airborne particulate monitoring system is upgraded to include ten additional air sampling units, which are situated at various locations within the restricted area. The samplers are located near areas where radioactive materials are handled routinely as well as along the site boundary. Particulate filter samples are collected on a daily level and sampled for gross beta-gamma contamination. In addition, samples are sent offsite on a weekly basis for more detailed analysis such as a gamma spectrum analysis.

The benefit of the improved monitoring system is a greater level of confidence in evaluating the performance of the site and an ability to initiate remedial action when indicated in a timely fashion. The estimated differential cost for the improved monitoring system shown in Table F.14 is $1.86/m^3 ($0.05 ft^3).

2.3.2 Control of Infiltration and Erosion

2.3.2.1 Improved Trench Covers

Installation and maintenance of an adequate cover (cap) over the disposed waste is one of the more important (if not one of the most important) considerations at a near-surface disposal facility. The trench cap provides radiation shielding and an infiltration barrier to moisture. A properly designed and constructed trench cover is also important in helping to minimize erosion.

The role of the trench cap as an infiltration barrier is especially important. If significant quantities of water are allowed to infiltrate through the trench cap and contact the disposed waste, then some of the radioactivity contained in the waste may be leached from the waste and released into the environment. Optimal conditions at a disposal facility would exclude the contact of significant quantities of water with the disposed waste. Minimizing water movement into disposed waste also helps to reduce the rate of anaerobic waste degradation (Refs. 24 and 25).

In the reference facility discussed in Appendix E, the trench caps are assumed to consist of one meter of backfill to original grade, plus an additional one meter of soil added above the original grade. In this section, some example alternatives to the reference case are briefly investigated and their costs quantified. These alternatives include improved compaction techniques, thicker trench covers, and possible use of multiple moisture barriers.

Before these alternatives are discussed, however, a brief background review is presented regarding a number of potential different types of trench covers which have been investigated by EPA and others (Refs. 24-28). Some considerations regarding placement of a final ground cover (i.e., grass) are also briefly discussed. Space does not allow a more detailed discussion of the different types of potential trench caps or the considerations leading to placement and maintenance of a final ground cover; however, the interested reader may find additional information in the references cited.

2.3.2.1.1 Background on Potential Trench Covers

Within the last few years, considerable information has been collected and published regarding the design and installation of covers for disposal facilities. Much of this information, (References 24 and 26, for example) has been published by EPA in connection with solid and hazardous waste disposal. Another reference which was prepared by SCS Engineers under contract to the EPA Office of Radiation Programs, is entitled "Study of Engineering and Water Management Practices that Will Minimize the Infiltration of Precipitation Into Trenches Containing Radioactive Waste" (Ref. 27). Some of the potential trench covers analyzed by EPA and others (e.g., Ref. 28) include clay, soil additives, asphalt, plastic membranes, and concrete.

A widely recommended cover for disposal areas is a cover composed of natural clay minerals--e.g., montmorillonite, illite, kaolinite, etc. Natural clay deposits are widespread in the United States. Chemically, all clay minerals consist of hydrous aluminum silicates, but incorporate differing amounts of water and accessory ions such as calcium and magnesium. As stated by EPA (Ref. 24):

> "The ability of clay aggregates to swell and expand derives from the existence of ionic charges that attract surficial layers of molecular water, as well as the tendency of some clays, particularly montmorillonite, to absorb additional interlayer water molecules. Therefore, when clay particules contact water, the effective diameter of the particles is increased and concurrently available pore space is diminished, resulting in decreased permeability rates. Maintaining moisture content is therefore relevant to ensuring low permeability and liner effectiveness in containing leachate. Moisture content is also important to the degree to which clays can be compacted in order to achieve the lowest permeability possible. Some clays such as montmorillonite have a greater tendency to absorb water than other types. For each type, an optimum moisture level exists for maximum compaction."

Clay covers can be very effective as a moisture barrier. For example, Hawkins and Hart (Ref. 29) have reported that in tests at Oak Ridge National Laboratory, a cap of dry bentonite clay 2 inches (5 cm) thick placed under a 0.61 m (2 ft) soil cover was completely effective in preventing rainfall at an annual rate of 50 inches from entering disposal cells. Another advantage is that clay has a self-healing property and can tolerate some settling without a significant loss in effectiveness. However, some care is required in the cover application. A clay cap can be penetrated by insects, animals, and plant roots. In addition, dried clay has a tendency to crack, and efforts should be made to retain its moisture content. In addition, clay covers need to be protected from freeze-thaw cycles. It was recommended by EPA (Ref. 27) that covers having high clay contents be protected from freezing temperatures and from drying out by an additional layer of more permeable soil (e.g., a few feet thick) over the clay cap.

Natural clay deposits can contain substantial nonclay components such as sand and silt. These components reduce the sealant properties, but if in proper proportions, can improve the workability and ease of application of the cover and reduce the susceptiblity of cracking due to freeze-thaw cycles or from drying out. Nonuniform mixtures of clay and other material can result in locations of concentrated infiltration. Commercially available clay mixtures such as bentonite or volclay add to the expense of the clay but help to provide a more uniform quality. This does not mean that natural clay deposits cannot be used, but it does indicate the need for quality control during obtaining, mixing, and applying moisture resistant trench covers.

Soil additives (soil sealants) may be applied as liquids to disposal trench covers. Upon drying, the soil additives polymerize, and the resultant swelling forms a sheet around soil particles, thus forming a seal. Development of soil additives has been relatively recent, and they have been used to help stabilize mine tailings. Soil additives are expected to be low in cost, but their long-term effectiveness is currently questionable. Apparently, there is a problem regarding control of the polymerization process, resulting in some cases in incomplete seals. There is also an apparent problem regarding long-term stability to chemical and biological attack. Use of soil additives would therefore appear not to be presently viable as a primary moisture barrier. Soil additives could be used, however, as an inexpensive backup to a primary barrier such as a clay cap.

Asphalt (e.g., asphalt concrete, hydraulic asphalt concrete, soil concrete, hot liquid asphalt) could also be used as a trench cover, but would be more difficult and expensive to apply than, for example, clay. Asphalt is also subject to degradation when exposed to air and sunlight, and so an asphalt cover would need to be covered with a layer of soil. An asphalt cover (underneath a soil layer) would be more water-resistant than clay, as long as the asphalt layer is intact, and would also act as a barrier to intrusion by humans, plant roots, and animals. A potential problem, however, is that while asphalt is more self-healing than concrete, for example, it is less self-healing than a clay cover. Therefore, asphalt could crack severely under subsidence, losing some or all of its effectiveness. Minor cracking, however, would probably have only a negligible effect upon asphalt effectiveness.

Another potential problem is that if subsidence problems require repairs to trench covers, then the asphalt layer would make this task more difficult and expensive. Assuming that subsidence problems at a particular trench could be eliminated (e.g., from disposing in that trench only wastes having structural integrity), an asphalt layer in conjunction with a compacted clay layer could prove to be effective.

Plastic membranes include such materials as polyethlene, polyesters, polyvinyl chloride, butyl rubber, or nylon, and are frequently used as liners in holding ponds or at hazardous waste disposal facilities. Membranes are generally installed in sections, with one section heat sealed or cemented to an adjacent section. As long as the membrane is not punctured, permeability of water through the membrane is essentially nil.

Plastic membranes tend to degrade in sunlight, so they would require a protective soil cover if used as a trench cover. More importantly, some question exists as to the long-term resistance to degradation at a disposal facility. In any case, special care would have to be taken during installation of a membrane as a trench cover to prevent tears or holes from occurring during installation.

Finally, concrete could be used as a trench cover material. Concrete is brittle, however, and would tend to crack over time--particularly under settling conditions. The effectiveness of a concrete trench cover by itself as a moisture barrier would be problematical. If properly supported, however, concrete could be effective as a moisture barrier, in addition to a barrier to plants, animals, and human intruders. An example of added support could be the use of grouting to fill the interstitial spaces between (stacked) waste packages.

2.3.2.1.2 Final Covers

After a cover (cap) has been placed over a disposal trench, it is important that the cap be stabilized by a final cover (Refs. 24 and 25). A lack of such a final cover leads to uncontrolled water and wind erosion of the trench caps. Two types of final covers are in general use today: natural vegetation (e.g., grass), and a hard surface cover such as cobbles or rip-rap.

A natural vegetation cover at a disposal facility can serve several functions, such as physically stabilizing earth materials, reducing erosion and infiltration of precipitation infiltration into the disposed waste, and enhancing the appearance of a site. A thick grass cover, for example, breaks the impact of falling water droplets on the earth surface, and reduces the run-off rate from the site, thereby reducing the potential for water erosion. By the same token, the plant roots help to hold the soil in place, thereby minimizing wind erosion. Reducing the rate of run-off, of course, also has the effect of increasing the amount of water infiltrating into the trench caps. However, some of the precipitating water will be caught upon leaves and other plant surfaces and will tend to evaporate rather than infiltrate into the soil. In addition, some of the water infiltrating into the trench caps will evaporate out of the soil surface. Water absorbed into plant roots may also be transpired through the plant leaves.

These processes of evaporation and transpiration--termed evapotranspiration--can result in a substantial amount of water being removed from soils. Evapotranspiration is enhanced by vegetation with dense root systems and a dense soil cover. It is important, however, that the root systems of cover grasses be of shallow depth to preclude contact with and uptake of radionuclides from the disposed waste. Examples of vegetation having shallow but dense root systems include hay, meadow grasses, and rye. Vegetation species native to the general area of the disposal site are preferable, as these species are more likely to be acclimated to the site climate.

Care needs to be taken when preparing the site for the final covering of vegetation--e.g., grading, spreading fertilizer, and mulching. If top soil removed from initial excavations is stock-piled, then this can be replaced on the completed trench cover to help promote plant growth. It has been observed that in the past at some facilities, miscellaneous fill has been used to repair cracks and sinkholes caused from trench subsidence. The fill is often devoid of essential plant nutrients. Growth of a soil cover is naturally retarded in these spots, leaving bare spots which can persist for some time. This can result in areas showing localized signs of erosion, or result in areas having concentrated point sources of infiltration.

Soil fertility is also desired in that it helps to promote evapotranspiration. First, fertile soil produces a lusher plant growth for a given crop. Second, fertile soil leads to healthier plants, which photosynthesize more rapidly and increase the water demand on the soil system.

While not as aesthetic as a vegetation cover, a layer of rip-rap or cobbles can also be effective as a final soil cover. This technique is particularly useful in arid climates, where it is more difficult to establish a vegetative cover. Such a hardened layer, in addition to preventing wind erosion, is also effective in eliminating intrusion by burrowing animals.

2.3.2.1.3 Example Alternative Trench Cover Designs

There are three principal design options which are discussed below to provide added assurance aginst infiltration of water into disposal trenches. These options are: (1) use of more densely compacted trench caps, (2) use of thicker compacted trench caps composed of low permeable clay soil, and (3) use of additional moisture barriers within a thicker trench cap. These options were selected based upon the above review of potential alternatives and improved trench covers. A number of other alternative designs could be envisioned. However, these are adequate for the purposes of this environmental impact statement.

<u>Compaction</u>

Improvements in trench cap performance can be obtained through increased attention to waste and cover compaction. Until fairly recently, little attention has been paid to compaction of disposed wastes other than the compaction that can be achieved by application of several feet of trench cover, plus driving over trench covers with waste transport and other site vehicles. This is the case assumed at the reference disposal facility. Decreased infiltration and percolation through a trench cover (by reducing porosity and thus permeability) can be inexpensively achieved, however, through use of improved compaction techniques using commercially available compacting equipment such as vibratory compactors. Within the last few years, for example, the operators of a disposal facility located in a humid environment have employed a mechanical vibratory compactor to provide additional compression of disposed waste and compaction of filled trench caps. The disposal site operators have reported that use of the vibratory compactor has greatly reduced subsequent maintenance of filled and capped trenches (Ref. 31).

Soil compaction is a standard construction technique and for a particular type of soil, a particular relationship can be developed which relates the moisture content of the soil to the amount of compaction (the dry density of the soil). These relationships can be determined and graphed using laboratory techniques. For a particular soil, an optimum moisture content can be determined which results in maximum compaction (greatest dry density). In standard construction practice, specifications for compaction require the soil to be compacted near the optimum moisture content and to a dry density specified as a percent of the standard determined in the laboratory--e.g., 90% of the standard (ASTM 1557) laboratory maximum density.

In practice, a variety of equipment types may be potentially used depending upon the type of soil. Some of these are listed in Reference 32 and include sheepsfoot rollers, rubbertire rollers, smoothwheel rollers, vibrating baseplate compactors, and crawler tractors (D8 or greater size). Soil to be compacted would be applied in 6- to 12-inch lifts and several passes made to compact each lift to the desired density. The depth of compaction available using such equipment is on the order of zero to six feet (Ref. 32).

For an example calculation of differential costs, the reference disposal facility operators are assumed to lease a vibratory compactor and employ an additional heavy equipment operator to operate the compactor. The compactor would be originally used to compact the 1 m of earthern fill down to the approximate level of the original site grade. Then, the 1 m soil cap would be applied in reasonably uniform 20 to 31 cm (8-12 in) layers and compacted to a minimum 95% of the maximum compactible density test.

Unit differential costs for this option are calculated (see Table F.15) to be about $\$1.90/m^3$ ($\$0.05/ft^3$). The resulting benefit is expected to be a decrease in trench subsidence and maintenance requirements. However, as stated above, the depth of compaction only extends for a few feet below the surface. Therefore, the potential long-term trench cap subsidence would be reduced but would not be eliminated.

Thicker Clay Cap

Another option would be to utilize low-permeability soil materials (clay) for the cap. For example, an additional 2 meters of high-grade clay soil would cost an additional $\$8.40/m^3$ ($\$0.24/ft^3$), assuming that the additional clay soil would be imported at a cost of $\$3.50/yard^3$ from a borrow pit located approximately 10 miles from the disposal facility (see Table F.16). The additional 2 m soil thicknesses would be applied in 8-12 in layers and compacted using mechanical compaction techniques. A three meter thick compacted clay cap would cost an approximate additional $\$10.90/m^3$ ($\$0.31/ft^3$). After installation and compaction, the cap would be covered with overburden and graded prior to seeding.

Moisture Barriers

Other methods may be potentially used to reduce percolation through trench caps. These include, for example, installation of single or multiple "moisture barriers" within a thicker trench cap. In this section, unit differential costs for four moisture barrier cases are briefly examined. The cases examined are shown in Figure F.5. For moisture barrier Case A, a single natural material barrier

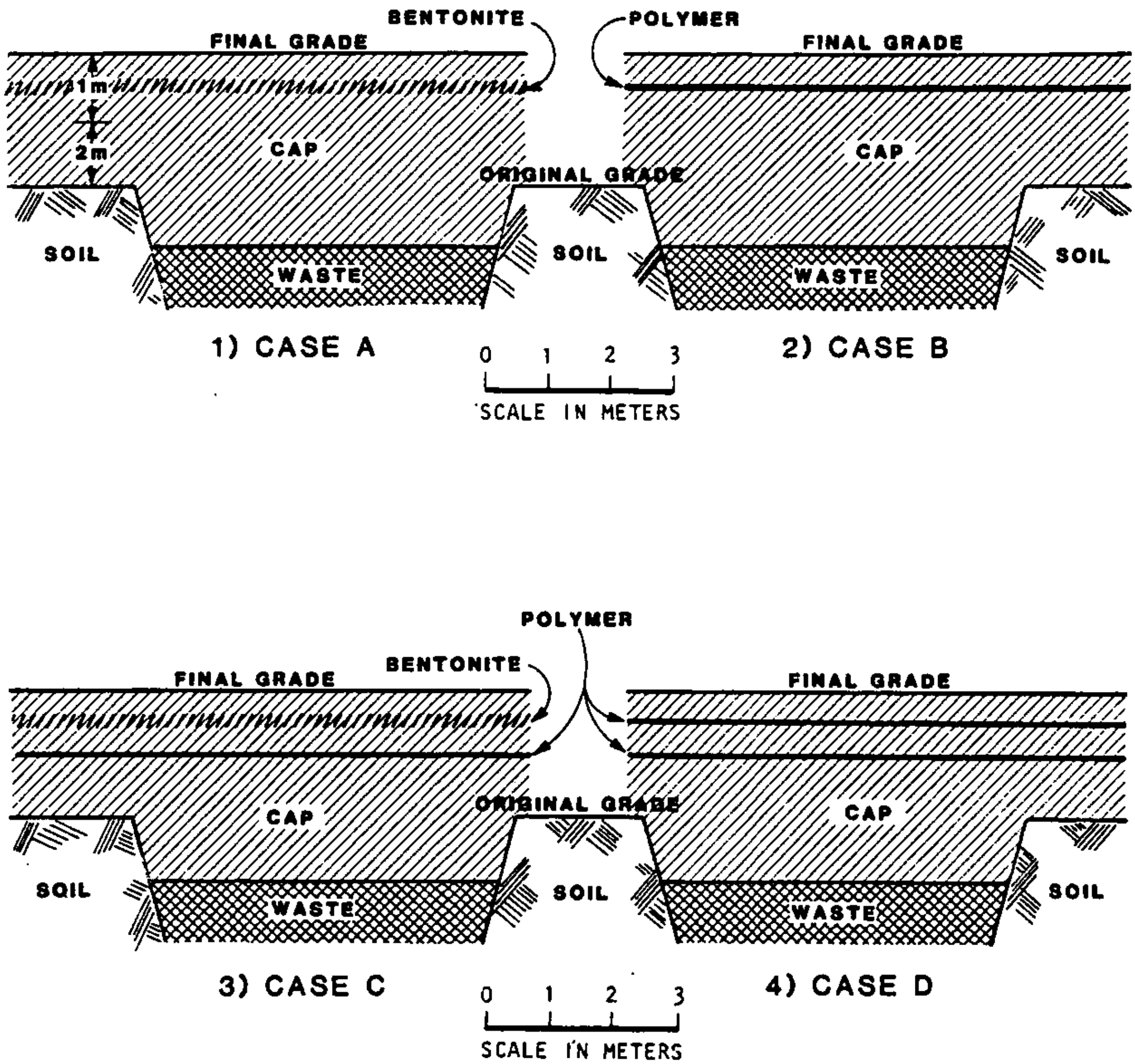


Figure F.5 Moisture Barriers

consisting of 4 pounds of bentonite per square foot is added to the above 2 meters of compacted clay soil. The bentonite layer is mixed at a depth approximately 0.5 m below the top of the compacted cap. This option results in additional costs due to the bentonite (or equivalent) layer, installation of the bentonite, import of offsite clayey soils, and grading and compacting the additional soil volumes. The estimated cost differential for application of the moisture barrier Case A (shown in Table F.20) is $14.80/m^3$ ($0.42 ft^3). This option affords the same attributes as the thicker lower permeability cap with some additional assurance of infiltration protection afforded by the inclusion of bentonite in the cap. Additional erosional protection could also be provided by revegetation in topsoil (greater chance of long-term survival of vegetation).

In moisture barrier Case B, a single polymer membrane moisture barrier is installed at roughly the midpoint of the additional soil thickness. The principal cost difference between Case B and Case A is the cost difference between the polymer membrane and the bentonite. The polymer membrane is assumed to be a 36 mil reinforced hypalon membrane which is installed on top of a mounded surface to promote drainage. The polymer membrane is assumed to have a permeability equivalent to or lower than the bentonite.

Polymer membrane have been shown to last up to twenty-five years (Ref. 33). (Polymer membranes have only been commercially available for this length of time.) However, if it is assumed that the membrane is sufficiently protected from ultraviolet radiation and thermal stresses, then it is possible that such membranes could retain their integrity for much greater lengths of time--e.g., perhaps up to 100 years. It should be noted that in the event of significant subsidence, a bentonite (or equivalent) moisture barrier has a higher probabilty of maintaining its integrity (clays can self-anneal under certain circumstances). The estimated cost differential between moisture barrier Case B and the reference facility (Appendix E) is $15.30/$m^3$ ($0.43/$ft^3$). This option affords the same general attributes that Case A does (namely, infiltration prevention, additional intruder protection, and additional erosion protection), with the only major difference being cost and perhaps a slightly greater degree of infiltration protection.

Moisture barrier Case C consists of two barriers: (1) a bentonite barrier, and (2) a polymer (36 mil reinforced hypalon) barrier. The polymer membrane is installed at the midpoint depth of the additional 2 m soil thickness, and the clay barrier is installed at or near the original ground surface. The polymer membrane is installed deeper to provide added protection against thermal and ultraviolet stress. The membranes are installed on mounded surfaces to promote drainage. The costs of Case C are identical to Case B with the addition of the cost of a polymer membrane. The estimated cost differential between moisture barrier Case C and the reference facility described in Appendix E is approximately $18.30/$m^3$ ($0.52/$ft^3$). This option affords the same positive attributes as Cases A and B, with the added assurance afforded by a redundant barrier system.

Moisture barrier Case D consists of two polymer membranes (both 36 mil reinforced hypalon). The membranes are similarly (to Case C) installed at a depth of 1.5 m

(4.9 ft) and 3.0 m from the final grade on mounded surfaces to promote drainage. The only cost difference between Case D and Case C is assumed to be the cost differential between the bentonite barrier and the polymer membrane barrier. The estimated cost differential between moisture barrier Case D and the reference facility is approximately $18.80 m^3/($0.53/ft^3). Case D offers the same positive attributes as Case C, including the redundant barrier protection.

The differential costs of the thicker clay cap and moisture barrier options are summarized below:

Case	Cost $/m³
Thicker, denser cap (2 m)	$ 8.41
Thicker, denser cap (3 m)	$10.89
Moisture barrier Case A	$14.83
Moisture barrier Case B	$15.30
Moisture barrier Case C	$18.34
Moisture barrier Case D	$18.81

As illustrated above, a number of alternative trench cap designs could be used at near-surface disposal facilities. These designs cover a range of costs, but none involves a significant increase in overall operational costs. The problem is that the benefits (at additional time and expense) from constructing the caps will be significantly reduced as long as potential subsidence problems exist at the site. Increased attention to compaction, using the mechanical compacting equipment, is expected to reduce the degree of subsidence. Further significant improvements in trench stablity are discussed in Section 2.3.3.

2.3.2.2 Infiltration Contact Time

The quantity of radioactivity that is leached from a given waste form is a function of the degree to which water is allowed to contact the waste form. The function of the improved disposal trench covers discussed in the preceding section is to minimize the amount of water that can infiltrate into the disposal trenches and contact the disposed waste. This reduces the amount of radioactivity that could be leached from the waste. A further reduction in the amount leached can be obtained through minimizing the time that infiltrating water is allowed to contact the waste. This can be accomplished by using highly permeable material (e.g., sand) as a backfill.

As discussed in Appendix G, the contact time with disposed waste for water percolating down through trench backfill would be greater for backfill composed of lower permeable soils than for backfill composed of higher permeable soils. This is because the speed of the percolating water is higher for materials with higher porosity than for materials with lower porosity. Use of a sandy backfill, then, would allow percolating water to quickly flow past disposed waste to the bottom of the trench, thus reducing the contact time and the potential for leaching. Use of a sand backfill would also be expected to readily sift down into the interstitial spaces between waste packages and therefore help reduce the presence of voids in a disposal trench.

A layer of sand--perhaps 6 inches to a foot thick--could also be placed at the bottom of the disposal trench prior to waste package emplacement. This would reduce the possibility of rainwater falling on an open trench, or water percolating through a closed trench cap, from collecting and standing around the bottom waste packages. This is especially important when one considers that at existing disposal facilities higher activity waste packages are frequently emplaced on or near the bottom of the disposal trenches to reduce radiation exposure to facility personnel. Water percolating to the bottom of the trench will percolate below the bottom waste packages into the sand layer, and flow into the French drain along one side of the trench. The French drain then directs the water to a sump at the low end of the trench before the percolating water has a chance to contact the lowest waste packages for extended periods of time. The sand layer also provides a smooth trafficable foundation for operation of vehicles such as fork lifts in the trench.

To implement this option, the disposal trench is assumed to be excavated an additional 0.15 m (6 in), and after the French drain, sumps, and standpipes are installed, a layer of sand 0.15 m thick is spread smoothly across the floor of the trench. Thus, the trench volume utilized for waste disposal remains the same as for the reference facility, as well as the height of the waste above the water table. The remainder of the disposal operations remain the same as before, with the exception that the sand backfill is utilized instead of backfill composed of previously excavated site soils. The 1 m space between the top of the waste and the top of the trench is also filled with the sand backfill. The backfill is obtained from a local borrow pit.

Assuming one million m^3 of randomly disposed waste at the facility, approximately 65,000 m^3 of sand would be required annually, or approximately 1.3 million m^3 over the 20 years operating life of the facility. This would result in an additional operational expense of approximately \$6.70/m^3 (\$0.19/ft^3) above that for the reference facility (see Table F.18). The added expense, however, is believed to be justifiable considering the overall gain--i.e., the overall reduction in potential infiltration contact time with the waste. In fact, use of a sandy layer on trench floors in addition to use of a sandy backfill is presently part of standard operating practice at the Barnwell, SC disposal facility (Refs. 11, 34).

2.3.2.3 Surface Water Drainage

Surface water management at the reference facility consists of drainage control through grading of the site. Temporarily installed earth berms are used to direct flowing water away from open trenches which are being actively used for waste disposal. Table E.1 in Appendix E shows the annual run-off to be 151 mm out of a total annual precipitation of 1168 mm. Thus, only about 13% of the rainfall is expected to be carried off as surface flow, considering the flat to gently sloping character of the site and the clayey sand soils. The relatively low run-off is not likely to cause an erosion problem assuming that the soil is stabilized by such means as use of a good vegetative cover or a rip-rap layer.

Surface drainage improvement through the use of ditching and channelization can be useful in reducing the quantity of water which percolates into the soil. This is accomplished by transporting the runoff water from the site before significant volumes can infiltrate into the soil.

The following presents an example of one method which may be used to improve drainage from the site. The costs and effectiveness of similar types of drainage systems at a real disposal facility would be site-specific. However, the following example illustrates the magnitude of the costs involved.

An improved drainage network for the site is assumed to include a secondary system, a primary system, and a main discharge channel to carry runoff from the site (see Figure F.6). The secondary system runs along the spaces between the trenches and collects water flowing off of the sloped trench caps. The collected surface water is directed to the primary system which runs along the facility perimeter as well as along the two main access roads into the restricted area (the north-south roads bisecting the facility as shown in Figure E.11). The secondary system consists of shallow trenches with liners of corrugated metal (1/3 of a pipe section). The primary drainage system is a larger capacity lined ditch system which collects the flow from the secondary system and carries it to the main discharge channel. The primary system runs entirely around the perimeter of the site. Again, corrugated metal liners are used, although larger radius sections are used to provide greater capacity.

The primary drainage system discharges at several points into the main discharge channel which carries the discharge offsite to another drainage channel which ultimately drains into a stream. The discharged water would then flow into a river. The discharge channel is assumed to be 500 m long and consists of a trapezoidal channel with gravel lining. A flow-activated automatic run-off monitoring system is installed onsite in the discharge channel.

The estimated cost differential for installation of a surface drainage system (shown in Table F.19) is $7.47/m^3 ($0.21/ft^3). The anticipated benefit is an overall reduction in the amount of water which percolates into the site soils.

2.3.2.4 Weather Shielding

To reduce or eliminate the amount of rainwater falling into an open trench during disposal operations, a temporary structure such as a weather shield may be potentially employed. At some disposal sites (i.e., Oak Ridge), (Ref. 35) corrugated metal arch sections are used to cover narrow trenches which are left open for long periods of time. At other sites (i.e., INEL), (Ref. 36) tension structures or air-supported buildings with large clearspans are used to provide weather shielding.

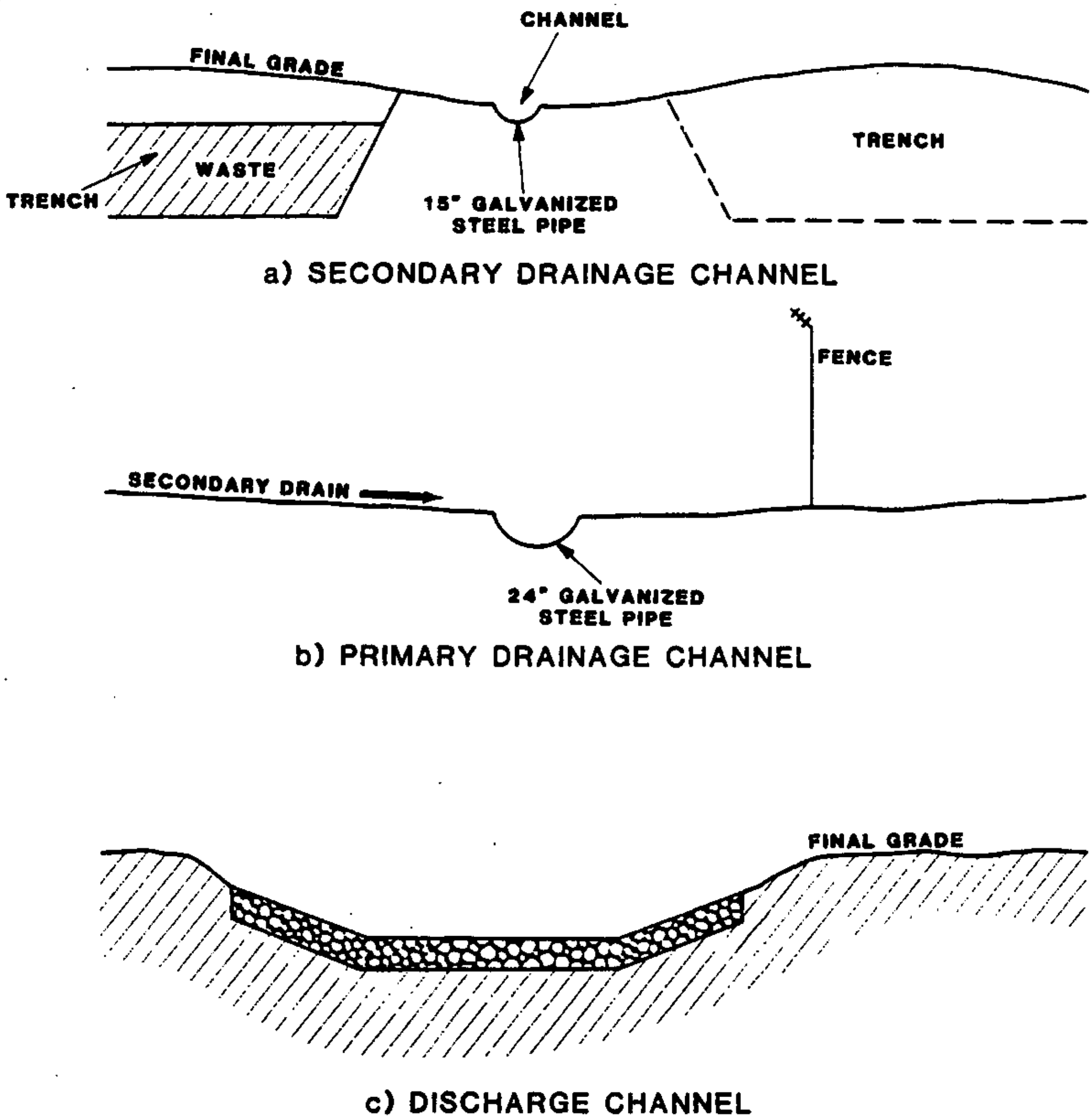


Figure F.6 Surface Drainage System

Use of weather shielding can result in additional waste handling problems. Even the largest weather shields have limited headroom. A tension structure with a clearspan of about 36 m can provide about 12 m of headroom at the center of the arch. This provides a serious limitation on emplacement of wastes from cranes located at relatively shielded positions at the ground surface. Most waste emplacement would therefore have to be performed by transporting the wastes directly into the trenches, and locating them by means of forklifts or small "cherry picker" cranes which operate directly on the trench floor. The use of weather shielding necessarily implies that the waste emplacement work force spends more time in relative proximity to the waste, and therefore higher occupational doses are anticipated. It is estimated that occupational doses will increase by about 15% with the use of weather shielding.

The weather shield assumed to be used at the disposal facility is a tension type structure in which a fabric is stretched over a series of arches to produce a completely enclosed free-standing structure. A shield having dimensions of 36.5 m x 190 m would be sufficient to enclose the entire surface of a standard trench. Access into the structure would be via standard hinged and large overhead doors located in the sides or ends of the structure. Once the trench is filled and capped, the structure would be dismantled and reassembled at another trench.

The estimated cost differential for the use of a weather shield in the disposal operations (shown in Table F.20) is $26.77/m^3$ ($0.76/ft^3$). The structure would greatly reduce or eliminate direct entry of precipitation in the open trenches. However, higher personnel radiation exposures would be expected to be experienced by the site staff as a result of the required in-trench handling operations. In addition, the cost estimate does not include costs for additional personnel or waste handling equipment that may have to be acquired to operate and emplace waste from within the disposal trench.

2.3.3 Control of Subsidence and Trench Instability

The major problem that has been experienced to date at near-surface disposal facilities has been subsidence of disposal trench covers. Subsidence problems observed at disposal facilities have ranged from minor settling and trench cap cracking to extensive cap collapse and creation of large-scale sinkholes. Subsidence is basically caused by the existence of void spaces within disposal trenches, including void spaces created by degradation of compressible material such as paper or other combustible trash. Problems which have been observed in the past at disposal facilities have included:

- Increased percolation of water into the disposed waste, resulting in potentially increased ground-water migration.
- Creation of leachate accumulation problems.
- Greatly increased site maintenance costs which were not expected when the waste was disposed.

- o At an arid western disposal facility, exposure of disposed waste which was then dispersed by wind.

- o A reduction in the ability to predict the long-term impacts of disposed wastes.

It is apparent that control of subsidence and assurance of site stability is of major importance in design and operation of a near-surface disposal facility. The following subsections discuss a number of possible facility designs and operating practices which may be used to help control, and possibly even eliminate, subsidence. These designs and practices all involve ways in which voids can be reduced in disposal cells and include waste emplacement techniques; waste segregation; use of caissons and walled trenches; more extreme compaction techniques; use of grouting and controlled density fills; decontainerized disposal; and increased volume reduction through onsite waste processing.

2.3.3.1 Waste Emplacement

In general, waste emplacement at existing disposal facilities is accomplished by either random disposal (including dumping or rolling containers into the disposal trenches, and placement of heavier items in a random fashion), or by stacked placement of items in some orderly or interlocking fashion. Stacked emplacement is used to either maximize trench space utilization or provide waste-shielded "pockets" in which higher activity containers may be placed. Past practices at commercial disposal facilities have ranged from completely random to entirely stacked disposal, with current techniques generally characterized by a mixture of random and stacked emplacement. Variations of stacked emplacement have been used, including individual placement of stacked boxes, large right cylinders, and some individual smaller (200 liter) drums in specific spots. In cavities formed by these first-layer containers, higher-activity waste may be placed. Lower activity waste may be then randomly stacked or rolled, depending on the mode of off-loading that is most efficient, on top of the first-layer containers. The stacking height is dependent on the types of containers received, the capabilities of the waste handling equipment, and the backfill required to maintain desirable radiation levels.

Waste stacking necessarily requires a segregation of waste according to characteristics such as geometric shape, stability, radiation levels, handling methods required for safe emplacement, and integrity of the package. For example, large boxes (containing low specific activity material) might be stacked in the trench less easily than setting the boxes on a trench edge and rolling the boxes in, but stacking is preferable since the box may rupture, and a stacked wall of boxed waste may be useful in controlling backfill spill-over down the working face. Drums, on the other hand, generally do not rupture as easily when rolled down the face of the trench and are typically stacked only when containing high levels of activity dictating individual handling. High activity waste may even be emplaced in separate preshielded disposal columns (e.g., toner tubes) to provide for additional radiation shielding to site personnel while further minimizing use of backfill. Excessive use of backfill reduces trench utilization efficiency. Other miscellaneous waste packages are either stacked or randomly dumped, depending on the time factor and the probability of container rupture.

An advantage of stacked rather than random placement of waste containers is that it enhances stability of the disposed waste, resulting from a reduction in trench void space and an associated decrease in the potential for subsidence. This promotes the integrity of the trench cover and reduces the infiltration of rainwater, thus reducing maintenance requirements as well as the potential for ground-water migration. Stacked emplacement is also estimated to improve the excavated volume use efficiency from about 50% to about 75%, resulting in an approximate 50% increase in trench capacity. Additional attractive features of stacked emplacement include a reduction of stresses on the integrity of waste containers, more control over high activity containers, and use of other waste (instead of backfill) for shielding. Where trench space is at a premium and a sufficient fraction of the incoming waste packages have uniform configurations for stacking, it may be to the operator's advantage to use this method.

There are also disadvantages to stacking of waste containers. Stacking is a more labor-intensive effort compared with random placement. For containers requiring individual attachment to offloading devices, such as large (170 ft^3) liners or high activity drums, a reasonably conservative increase in manpower (or decrease in waste emplacement rate) of about 20% over random placement requirements is estimated to occur. For smaller containers such as drums, which are often rolled off of transport vehicles into the trenches, the labor requirements are multiplied by a factor of about 4. This translates into an overall estimated increased labor requirement for waste handlers of about 1.5, compared with random emplacement of all container types. This not only increases the labor cost per unit volume, but raises worker radiation exposure levels proportionately. Where segregation of high activity waste is not performed, trench radiation levels may at times prohibit workers from assisting in the desired positioning of containers.

The anticipated impacts on operational costs are reviewed in Table F.21. As shown, use of stacked disposal is estimated to result in an increased cost differential of \$22.24/m^3 (\$0.63/ft^3). Overall radiation doses among waste handlers would also rise. These additional exposures could be reduced if stacked disposal was carried out concurrently with a program to segregate wastes having higher surface radiation levels.

2.3.3.2 Waste Segregation

Waste segregation is separation of waste materials at the disposal facility in accordance with specific characteristics. This may be according to isotopic content, chemical content, activity, container size, shape, or structural stability. Some forms of waste segregation are in use already at both government and commercial disposal facilities. Existing packaging, handling, and disposal restrictions on waste packages containing special nuclear material are one example. In addition, differing site acceptance criteria have forced some segregation of waste among the commercial facilities still in operation. Other practices have been used with less consistency, such as separate disposal of high-activity wastes in "hot wells".

Most existing waste segregation practices are based on the radiation hazard of waste packages. For wastes having high surface radiation levels which could require use of extensive backfill if mixed with the main body of waste, it may be more cost effective to use specially placed caissons or slit trenches which afford improved shielding with little backfill volume required. Use of this segregation technique may also reduce radiation exposures received by facility personnel from high-activity waste by 20% or more. This is because less direct exposure time is incurred while transferring high activity waste to a deep excavation with vertical sides than to an open area where it must be covered to reduce lateral exposure rates.

Two examples of wastes which are prime candidates for segregation are wastes having high concentrations of organic chemicals and chelating agents and wastes such as compressible low activity trash for which long-term stability cannot be assured. Segregation of such wastes from other wastes will result in overall improvements to the potential for ground-water migration. With unsegregated waste disposal, nuclide migration from a trench would be based on limiting isotopes and worse case conditions. With segregation, the most innocuous wastes having limited activity and short half-lives could be disposed of in trenches engineered to contain that waste over its hazardous lifetime with a high confidence level. More hazardous and longer half-life wastes could concurrently be disposed in appropriately engineered (more expensive) disposal areas allowing greater controls to be utilized in a cost-effective manner on that small fraction of the more hazardous waste. Although this concept is not a radical departure from current techniques, it will require that wastes requiring segregation from other wastes be identified on shipment manifest documents.

A summary of the overall costs of waste segregation is included in Table F.22. These additional costs are expected to be relatively minor--i.e., an additional $6.08/m^3$ ($0.17/ft^3$) in unit disposal costs. An additional benefit could be in overall dose reductions to site crews from segregated disposal of high activity wastes. These overall reductions in workers' exposures could be as much as 20%.

Proper segregation of wastes is dependent on cooperation from the waste generator. The waste generator must provide sufficient information in radioactive shipment records regarding the package contents to enable the disposal facility operator to properly classify the waste. This administrative tool, properly applied, and coupled with a few minor modifications in operations, can result in overall improvements in waste disposal.

2.3.3.3 Decontainerized Disposal

Decontainerized disposal refers to emplacement of low activity wastes divested of any external shipping container. Presently, wastes such as bulk low activity material (e.g., low activity thorium wastes, zirconium sands, calcium fluoride wastes) or large pieces of machinery are occasionally disposed at disposal facilities without external shipping containers. Considered in this section is the potential option of extending this disposal technique to other low activity wastes such as dry trash and biological wastes. The key factor is the absence of a container which would temporarily isolate the waste from the soil backfill. A major question is how to effect waste removal from a shipping container in a safe, efficient (economical) manner and dispose of the waste in an equally safe, efficient manner.

For decontainerized disposal, waste streams are assumed to be disposed of by methods similar to that employed at a sanitary land fill. Waste would be emptied from containers onto the ground and covered over periodically with a soil layer using heavy equipment. The waste containers could then be decontaminated and reused.

Benefits would be realized both during and after disposal operations. The absence of containers will reduce the waste volume somewhat, with additional savings occurring through container reconditioning and reuse. However, the major advantage is anticipated to come from accelerated stabilization of disposal trenches by allowing soil chemical action and equilibrium to occur within the waste without the time lag from container degradation.

A major disadvantage is the current lack of some prerequisite conditions and techniques. The current nonsegregation of radioactive forms does not allow wholesale utilization of decontainerized disposal. Additionally, decontainerization of medium-to-high activity wastes would not be advantageous because of the accompanying hazards of direct gamma radiation and potential airborne contamination to the waste emplacement labor force. A minor fraction of this concentrated waste becoming airborne could constitute a large hazard to the disposal crew, and affect the local offsite environment.

Another difficulty for decontainerized disposal is development of viable emplacement techniques. A significant industry-wide change would evolve from the concept of reconditioning transport containers. This would also indicate need for additional decontamination and waste treatment facilities with additional manpower requirements at the site itself.

Actual empirical data is not available on the increase in manpower and equipment requirements for decontainerized waste emplacement. Based on an assumption of 50-60% of all waste received as being disposed of by decontainerized methods, the increase in labor is estimated to be a factor of 4-5 times that needed for random placement of containerized wastes. In addition, a means for opening a container and exposing the contents, transferring the contents to the trench, emptying the containers, and compacting a protective fill on the waste without excess exposure risk to persons, both offsite and onsite, will need to be developed. Performing this operation will require close proximity to many potential exposure hazards including direct radiation and airborne contamination. Increased requirements for monitoring of personnel (both internal and external) and equipment will be a prerequisite to licensing this type of operation. Possible use of clothing such as controlled-air anticontamination suits may also be required. A presorting operation would be needed to ensure that small pieces of high activity material are not contained in otherwise low activity waste material. The occasional presence of such high activity material could result in significant additional (accidental) exposures to site workers. A weather shield would be required in humid or windy areas. Increased trench and site perimeter airborne monitoring would also be needed.

Assuming that a method of emplacement is approved for decontainerized waste, a separate disposal area would be required, segregating this waste from other waste streams disposed of at the facility. An increase in crew size would be needed to offset the lowered efficiency per unit volume expected in this type of emplacement, and additional handling equipment would be required. Increased unit costs are shown in Table F.23, and are estimated to run in the range of $93.50 per cubic meter of waste disposed in a decontainerized manner ($2.65/ft^3) or higher.

Radiation worker exposures would be expected to rise proportionately to the increase in work force. As discussed above, the potential for additional accidental exposures would also be expected to be greater than for the reference case.

2.3.3.4 Compaction to Greater Depths

Section 2.3.2.1.3 discussed use of standard construction techniques using heavy machinery (vibratory compactors, sheepsfoot rollers, etc.) to compact backfill into disposal trenches followed by compaction of the disposal trench cap. This compaction is expected to help compress disposed wastes and reduce voids, thus reducing settlement and subsidence problems, infiltration of water, and potential migration of radionuclides. Maintenance requirements would also be reduced. The depth of compaction achieved by these standard construction techniques is only a few feet, however. Thus, shallow compaction would not be expected to completely eliminate potential subsidence as long as a significant amount of compressible waste is disposed in the disposal trench.

Additional construction techniques, which have never been used at LLW disposal facilities but which could be considered as expensive means to achieve very deep compaction (e.g., down to the bottom of a disposal trench), include pile driving and dynamic consolidation. Both methods have been considered for potential application at the Sheffield, Illinois disposal facility (Ref. 33).

Pile driving as a means to densify deep soil deposits--particularly loose cohesionless soils--has been practiced for several years. In this technique, wood piles would be driven in a close grid pattern through the disposal trench cap and into the disposed waste. Compaction would be achieved through displacement of the soil/waste mixture by the piles as well as by vibrations generated through driving the pile. After driving, the piles could be potentially removed and holes filled with low compressive material such as cement or backfill. The piles could then be reused in another location. A problem with this would be that the piles would become contaminated as a result of contact with the waste materials. This contamination would then be available for transfer to workers or equipment or become dispersed into the air, thus becoming an occupational as well as an offsite radiation hazard. The removed piles would eventually have to be disposed as radioactive waste. As an alternative, the driven piles could be cut off at ground level and covered with a compacted cap. This would result in significantly increased expenses, however.

Dynamic consolidation (or dynamic compaction) is a relatively new (25 years) construction technique which, while not previously used at radioactive waste disposal facilities, has been used to reduce settlement problems at landfills. The technique has been developed by Menard (Refs. 37, 38) and has principally been used in Europe. In practice, a large (5-40 ton) weight is dropped from a significant height (e.g., 20-100 ft) several times over a limited area. For an area such as a disposal trench, an optimum weight and drop height would first be determined. Then, a crane would drop the weight a number of times at several locations in a pattern across the trench cover surface. Depressions left by the weight would be filled in and additional passes over the trench surface may be made as desired and depending upon site-specific conditions.

The impact of the dropped weight is believed to cause partial liquefaction of granular and nonsaturated soil, which allows the soil mass to settle into a denser state. For saturated cohesive soils, it has been hypothesized that the shock waves and high stresses caused by repeated high energy impacts result in gradual liquefaction and consolidation of the soil. The method is reported to be effective to depths of 15 m (50 ft) and can achieve surface settlements of 5 to 15% of the deposit thickness (Ref. 33).

Other than the expense, the principal drawback to this compaction technique is the potential for expulsion of contaminated soil and waste. Depending upon the characteristics of the soil, the weight employed, and the drop height, depressions having depths of up to several feet may be produced. Care would have to be taken so that the dropped mass did not penetrate the cover material to the point that the waste is contacted and/or expelled into the air. As in the case of the piles, this would cause a contamination problem for personnel and equipment, not to mention an airborne hazard both onsite and offsite.

One way to reduce the potential for airborne spread of contamination would be to restrict the mass of the weight and the dropping height. However, this would also diminish the effectiveness of the compaction technique in that the depth of compaction would be reduced.

In any case, an example economic calculation is performed in Table F.24 for dynamic compaction of the 58 disposal trenches. As shown in Table F.24, this is estimated to result in an additional $\$18.61/m^2$ ($\$0.51/ft^3$).

2.3.3.5 Engineered Supports for Disposal Trench Covers

As discussed in the previous sections, waste stacking, waste segregation, and deep compaction all appear to offer improvements in the ability to reduce voids and to control (and possibly eliminate) subsidence. Decontainerized disposal could also be used to help reduce trench subsidence, and would be useful for such wastes as low activity bulk solids, contaminated building rubble, or occasional large pieces of machinery, provided that disposal of such wastes was carried out in an operationally safe manner. However, decontainerized disposal currently appears to be a nonviable option for general extension to all wastes.

This section discusses optional disposal methods involving construction of engineering supports for trench caps. The types of engineering supports addressed include caisson disposal, walled trench disposal, and grouting and controlled density fill. These disposal concepts were previously introduced in Section 2.2 regarding their potential use as barriers to the potential inadvertent intruder.

2.3.3.5.1 Caisson Disposal

Caisson disposal was discussed in Section 2.2.2.3 as a means of reducing exposures to site personnel during waste disposal operations as well as reducing potential impacts to a future inadvertent intruder. Caissons may also be used as a means of providing support against subsidence and of reducing potential ground-water impacts particularly for an occasional high activity waste stream. It does not appear, however, that caisson disposal would be suitable for disposal of all of the waste delivered to the disposal facility. In Section 2.2.2.3, differential costs were calculated for an example in which 10% of the waste delivered to the reference disposal facility (about 100,00 m^3) were disposed in caissons. These differential costs were estimated to be about $216/$m^3$ ($6.13/$ft^3$). In the calculations, the number of caisson trenches constructed was 2,585, replacing 6 reference trenches, and about 17 additional acres of land was committed to waste disposal. If caissons were used to dispose of all of the waste, then 25,000 such caisson trenches would be constructed and the additional land area raised to about 170 acres. Costs would also be high.

In addition, much of the wastes which would be thus emplaced in caissons would be of very low activity, and use of this more elaborate disposal method may not be necessary to ensure protection of public health and safety. Another problem would be that caisson disposal would be unwieldly and inefficient for odd-shaped waste such as contaminated machinery or disposal of wastes shipped in large boxes.

2.3.3.5.2 Walled Trench Disposal

Walled trenches were previously discussed (in Section 2.2.2.4) as a method of reducing exposures to site workers and to a potential inadvertent intruder. Walled trenches may also be used as a means of providing structural support for trench covers. The cost and land use differential for walled trench used for 10% of the waste received at the site was estimated in Section 2.2.2.4 to be $256/$m^3$ ($7.25/$ft^3$) and 4 acres, respectively. If walled trenches were used for all wastes at the facility, the unit differential cost would be $161/$m^3$ ($4.50/$ft^3$) and the additional land use 39.5 acres.

2.3.3.5.3 Grouting and Controlled Density Fill

Another method available to reduce subsidence is to fill the void spaces between waste packages with a material that will help support the trench cap before emplacement of the trench cap. The types of agents available for void space filling include clay (bentonite) slurries, grout, and controlled density fill. The use of slurries may not be practical since it involves introducing quantities of liquids over time. Conversely, grouts and controlled density fills generally set into solid form with little or no residual liquids.

For illustrative purposes, two cases of void space minimization are considered in this appendix. As discussed in Section 2.2.2.5, the first case involves the use of grout which is pumped into the void spaces between stacked waste containers before backfilling. The estimated differential cost for this disposal option is $38.22/$m^3$ ($1.08/$ft^3$). The resultant benefits include greater trench cap integrity, additional intruder protection, and increased resistance of the waste to leaching.

The second case involves use of controlled density fill in place of the cement grout. In this example, the controlled density fill is assumed to be a commercially available lower strength concrete (e.g., K-crete, Mearlcrete). The estimated differential cost for the controlled density fill is $24.62/m^3$ ($0.70/ft^3$). Other than cost, the only appreciable difference in the final trench status is the overall strength of the fill. Controlled density fill will adequately support the trench cap but is more capable of being excavated. The benefits to trench cap integrity and leach resistance are assumed to be equivalent to that for grout cement.

2.3.3.6 Centralized Waste Processing

One distinct disposal technology option available is additional volume reduction of waste in a centralized location. Of the 50,000 m^3 (1.77 million ft^3) of waste that arrives annually at the reference disposal facility, approximately 20% (or 10,000 m^3) could be significantly reduced in volume at a regional processing facility by either compaction or incineration. It should be noted that a larger fraction of all potential waste volumes destined for disposal sites can be significantly reduced in volume. However, it is believed that large volume generators can probably perform volume reduction at the point of waste generation. It will generally be the low volume generators such as hospitals, academic institutions, and various industrial facilities which may not have the facilities or the economic means to perform volume reduction at the point of generation. The types of waste streams that appear most amenable to centralized or disposal site processing include contaminated trash from institutions (e.g., hospitals and universities), source material and special nuclear material trash, and low-activity trash from industrial radioactive material licensees. (See Appendix D for a discussion of these waste streams.)

In this appendix, three centralized waste processing options are considered:

1. Compaction of institutional compactible trash and industrial low activity trash is performed using a compactor/shredder capable of achieving a volume reduction factor of between three and four. Compaction not only increases the available volume capacity of the reference disposal facility but also increases the overall stability of the disposal trenches. Assuming a fixed annual volume input to the reference disposal facility, compaction of 10,000 m^3 of compressible wastes to a volume of approximately 2,500 m^3 results in a reduction of the land area which must be committed to waste disposal from about 35 ha (87 acres) to about 30 ha (73 acres).

   The compaction facility includes the compactor/shredders, the compactor building, and a small storage area. The compaction facility requires two full time personnel for operation. This compaction facility is assumed to be situated on the 52-acre parcel of land owned by the site operator immediately adjacent to the leased disposal site property. The estimated cost for compaction of waste at the compaction facility is $503/m^3$ ($14.25/ft^3$).

2. The above waste streams are incinerated using a fluidized bed incinerator. Depending upon the waste streams incinerated, a volume reduction factor of between 40 and 80 is achieved prior to solidifying the resultant ash in a suitable binder. It is likely that the principal wastes processed by the fluidized bed incinerator at the regional facility will be contaminated trash from small institutions and industry. Of the annual waste input of 50,000 m^3 (1.77 million ft^3) to the reference disposal facility, approximately 5,100 m^3 (roughly 10% by volume) is combustible waste from small waste generators, and therefore amenable to incineration at a centralized location. The estimated differential cost for incineration at this facility is $1,039/m^3 ($29.43/ft^3). More detailed descriptions of incineration can be found in Appendix D and Reference 39. The benefits of incineration include decreased land use and greater trench stability.

3. The above waste streams are incinerated as in option no. 2. In addition, an industrial hydraulic press is installed which is capable of achieving an overall volume reduction factor of 6.0. Waste streams which are assumed to be compacted via the hydraulic press include PWR noncombustible trash, BWR noncombustible trash, and fuel fabrication plant noncombustible trash. The estimated unit cost for compaction of these three waste streams is $1,006 per m^3 of input waste ($28.49/ft^3).

Centralized waste processing operations may take place at any suitable location within a region. For convenience, however, processing activities are assumed to take place upon a parcel of land immediately adjacent to the reference disposal facility. The three centralized waste processing options correspond to the assumptions of waste spectra 2, 3, and 4 as described in Appendix D, and are derived from information obtained from References 39 and 40.

3. LAND DISPOSAL ALTERNATIVES TO NEAR-SURFACE DISPOSAL

The disposal options reviewed in Section 2 of this appendix represent variations in near-surface disposal technology. In this section, land disposal alternatives to near-surface disposal are discussed. The two principal disposal alternatives addressed in this section are disposal in intermediate depth excavations (greater than 15 m depth) and disposal in deep-mined cavities.

3.1 Intermediate Depth Disposal

Intermediate depth disposal is assumed in this appendix to mean disposal of waste at depths greater than 15 m (49 ft). (In Section 2.1.1, deeper burial was briefly considered--but was restricted to depths on the order of 16 m (52 ft).) While five meters represents the maximum expected depth for small construction and farming activities (excluding well drilling), the maximum expected depth for heavy construction activities (excluding surface mining) is probably less than 15 m. Deep burial at some localities (especially many areas in the humid eastern United States) may be difficult as a result of relatively shallow depth to ground water and heterogenous subsurface media (e.g., fractured rock). However, it is believed that intermediate depth disposal could easily be practiced in a number of areas in the western and southwestern U.S. Perhaps a suitable location could be located in the eastern U.S.

The use of deep trenches appears to have limited applicability. As previously stated, in the humid eastern U.S., the number of locations amenable to a deep excavation (35 to 50 m) without encountering either ground water or fractured media is probably quite small. Additionally, the practicality of construction of a deep trench may be questionable from both a side slope requirement and an operational requirement. The large depth excavation would require (if excavation as a trench were feasible) either substantial shoring to keep the excavation open or would would require terracing or gentle slopes. Once the slopes are terraced or gently sloped, the excavation then begins to resemble an open-pit mine or strip-mine geometry. Another drawback to using very deep trench excavations is the potential difficulty in waste emplacement. Existing conventional lifting equipment would not be adequate. Either modified mine hoists or dumping would be required. Use of hoists could significantly increase the labor requirements in elevated radiation fields while dumping wastes into deep excavations would probably rupture many waste containers.

Application of strip-mine or open-pit mine technologies appears to be more viable options. Surface mining technologies can be applied to either existing mines that have not been fully reclaimed or to new sites where geologic conditions would permit such large excavations. (It should be noted that the principal goal of the application of intermediate depth disposal is to provide added protection for the inadvertent intruder. The majority of radioactive waste commercially generated will not require such extensive protection for the inadvertent intruder.) For purposes of analyses, an average annual waste input of 50,000 m^3 (1.77 million ft^3) over 20 years duration is assumed.

The example intermediate depth disposal facility can be accommodated on a leased tract of land equivalent to that described for the reference disposal facility (approximately 60 ha (148 acres)), including the excavation itself, the administrative area, overburden storage areas, and waste activities buildings and staging areas.

Both the design and operation of the intermediate depth disposal facility differ significantly from the reference disposal facility described in Appendix E. The excavation is assumed to be a circular open-pit with a spiral access road leading down into the excavation. The excavation is roughly circular with a 410 m diameter at the base of the excavation and a 480 m diameter at ground surface. The maximum depth of the excavation is 34 m. The disposal cell consists of three layers of waste each 5 m thick. Each layer of waste is emplaced by forklifts and boom cranes within the excavation. Random emplacement is assumed throughout the operations with a void space utilization of 50% assumed.

After the final waste layer is emplaced, a final disposal cap of 15 meters of overburden is added, which results in a minimum thickness of 15 m between the waste and the final grade. The equipment needs for the intermediate depth disposal are similar to the reference disposal facility, with the addition of 3 forklifts for waste emplacement activities, 2 pan scrapers to handle the extra overburden volumes, 4 dump trucks to supplement earth moving activities, and 2 extra cranes for waste emplacement. The building and structure requirements are assumed to be similar to those required for the reference near-surface disposal facility described in Appendix E.

The labor requirements for the intermediate depth disposal facility are increased as a result of the need for additional heavy equipment operators, dump truck drivers, semiskilled labor, and unskilled labor. The overall unit disposal (design and operation only) costs for intermediate depth disposal are $238/m^3$ ($6.75/ft^3) for disposal in an existing mine site (not fully reclaimed), and $344/m^3 ($9.75/ft^3) for a new site. This results in an increase over the design and operating costs of the reference facility of $53/m^3 ($1.50/ft^3) and $159/m^3 ($4.50/ft^3), respectively. It is assumed that the site for either option is located in a semiarid or arid portion of the U.S., precluding large dewatering requirements. The major benefits of intermediate depth disposal include significant protection for the inadvertent intruder as well as some increased ground-water protection. The major disadvantages are higher costs.

3.2 Mined Cavity Disposal

The two basic options available for mined cavity disposal are: (1) creation of a new mined cavity for disposal, and (2) rehabilitation of an existing mine for disposal. Construction of a new mined cavity can be accomplished either in salt media or in hard rock media (e.g., granite or basalt). One significant variation from a near-surface disposal facility is the land requirement. To control access to the mine and prevent intrusion (especially in the form of well drilling), between 1,000 and 1,400 acres of surface property are assumed to be acquired for a mined cavity capable of handling one million m^3.

The disposal horizons for the example newly constructed salt-mined cavity is assumed to be 549 m (1,800 ft) below the ground. The example rehabilitated salt mine is assumed to be 325 m (1,066 ft) below the ground. The room and pillar design is the geometry assumed for both new mined cavity disposal sites and for rehabilitated sites. The initial capital outlay for a mined cavity disposal is considerably higher than that for a near-surface disposal facility ($40 to 60 million as opposed to $7.5 million). The significant components of capital investment include underground equipment (e.g., continuous mining machines and trucks), surface equipment (e.g., waste handling equipment), surface facilities, and the construction of four shafts (i.e., waste, worker, air intake, and air exhaust).

Compared to a near-surface disposal facility, a number of additional surface buildings and facilities are required for a mined cavity disposal facility. The additional surface facilities include: a waste receiving building, cap and powder magazines (for hand-rock mining only), a hoist building, and an electrical substation for underground power requirements. A significant area (10 ha or 25 acres) would have to be set aside at each mined cavity disposal site for mined material storage (new mines only).

Disposal operations require relatively close contact with the waste packages. Waste is handled, in effect, twice: once at the receiving building, and once within the mined cavity. As a result of the double handling and the confined working areas, it is estimated that the occupational exposures for mined cavity operation for one million m^3 of waste are about four times higher than those experienced at a near-surface disposal facility. A large mined cavity disposal facility will require between 150 and 175 persons on the payroll (over twice the requirement for a near-surface disposal facility). While a near-surface disposal facility will require approximately 40 people to work directly with the waste (intermittent or continuous work), a mined cavity facility will require between 80 and 100 persons working directly with the waste.

The estimated cost for mine cavity disposal, assuming disposal in salt, ranges from \$512/m^3 (\$14.50/ft^3) to \$839/m^3 (\$23.80/ft^3). These costs are design and operating costs only and represent an additional \$327/m^3 (\$9.26/ft^3) and \$654/m^3 (\$18.52), respectively, over design and operating costs of the reference disposal facility. The lower range of costs is representative of the costs for a rehabilitated mine.

4. ALTERNATIVES TO LAND DISPOSAL

The two alternatives to land disposal discussed in this section are ocean disposal and space disposal.

4.1 Ocean Disposal

The United States Atomic Energy Commission (AEC) previously licensed disposal of low-level radioactive waste at a number of Atlantic and Pacific Ocean sites. The disposal site locations varied greatly in terms of distance from shore and depth to disposal area. In the early 1960s, the AEC began to phase out ocean disposal of radioactive waste, and by the end of 1970, all the U.S. ocean-related disposal activities had ceased. Ocean dumping up to this time had been conducted at 5 different locations in the Pacific Ocean, one location in the Gulf of Mexico, and 11 locations in the Atlantic Ocean. The waste was not evenly distributed among the 17 disposal sites, as two Atlantic sites and one Pacific site received about 90% of the low-level radioactive volume disposed at sea (the Pacific site actually consists of two subsites). The locations and waste volumes disposed of at the four principal disposal sites are shown in Table F.1 (Ref. 29).

Although not currently practiced in the United States, ocean disposal of radioactive waste is practiced by several foreign countries. The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) developed a program which, in 1967, led to the first international disposal operation involving five countries. Additional international organizations were carried out from 1969 through 1976, utilizing the International Atomic Energy Agency's (IAEA) guidelines to regulate operations of sea disposal of

Table F.1 Summary of Past Ocean Disposal Practices

Site	Location (Lat/Long)	Depth (m)	Distance from Land (km)	Approximate No. of 55 gal Drums Dumped	Approximate Total Volume (m^3)
Atlantic Site "A"	38°30'N 72°06'W	2,800	190	14,300	2,970
Atlantic Site "B"	37°50'N 70°35'W	3,800	320	14,500	3,020
Pacific Site "A"	37°50'N 123°08'W	900	60	3,500	728
Pacific Site "B"	37°37'N	1,700	77	44,000	9,150

radioactive waste. The regulations encompassed site selection, packaging and container design, ship design, health physics, recordkeeping, and supervision of dumping operations.

In 1972, the International Ocean Dumping Convention (IODC) made specific recommendations which were adopted in 1974 by the IAEA. Not all radioactive-waste producing countries have adopted the IODC recommendations or those standards developed by the IAEA. Thus, international agreement on regulating ocean disposal activities for radioactive wastes is presently lacking.

In the United States, the EPA has the responsibility of developing a permit program for ocean dumping of all wastes, including radioactive waste as well as solid and hazardous wastes. EPA was provided with this regulatory responsibility by the Ocean Dumping Act of 1974 (PL 92-532) and since this law was passed, EPA has instituted a domestic criteria and standards development program.

There are two major concepts for sea disposal--ocean dumping of packaged wastes and sediment penetration using free falling projectiles containing several waste packages. The costs (including transportation costs) have been calculated by Reference 29 to be \$710/m^3 (\$20.10/ft^3) and \$2,200/m^3 (\$62.30/ft^3) respectively. However, many technical, legal and social issues regarding ocean disposal will require resolution in its use as a disposal technique.

4.2 Extraterrestrial (Space) Disposal

The concept of space disposal of radioactive waste has been under investigation for a number of years. Studies have focused almost entirely on high-level waste (HLW) disposal since the tremendous costs involved render this alternative nonviable for all but the most hazardous materials (i.e., highly concentrated fission products and transuranics). Currently this method is not considered cost-effective or technically feasible for HLW disposal, although studies are continuing. Advanced concepts in such technologies as isotope separation and low-cost heavy-lift launch vehicles (HLLV) may result in future application of this method for HLW.

The key to utilization of space as a waste disposal option is cost reduction. The largest cost item is the launching cost, which is dependent on both the capabilities of the launch vehicle and the destination of the payload. Eight potential methods (destinations), some of which isolate the waste within the solar system (e.g., high earth orbit, solar orbit) and others which can be considered as permanent disposal methods (e.g., solar impact or solar system escape), are shown Table F.2 (Ref. 41). The costs associated with each destination is also given in Table F.2 in terms of dollars per pound of gross payload. These costs are 1972 estimates using the space shuttle for payload delivery to low-earth orbit (LEO) and an advanced centaur rocket to boost the payload to high-earth orbit (HEO), or to escape velocity. These costs must be considered nonconservative since the cost per pound listed is for the gross payload and does not consider the waste containers. In addition, the cost of shuttle launches has significantly increased since the 1972 study.

Table F.2 Cost Estimates for Space Disposal of LLW*

Destination	Launch Costs**				
	Shuttle		HLLV		
	$/lb	$/m^3	$/lb	$/m^3	10^9 $/year†
High Earth Orbit	628	2,200,000	27	94,000	24
Solar Orbit					
Single-Burn Earth Escape	628	2,200,000	27	94,000	24
via Mars or Venus	794	2,800,000	34	120,000	30
Double-Burn Circular Orbit	800	2,800,000	34	120,000	30
Solar System Escape					
via Jupiter	3,500	12,300,000	150	520,000	130
Direct	4,420	15,500,000	190	660,000	170
Solar Impact					
via Jupiter	4,700	16,400,000	200	700,000	175
Direct	Payload zero with existing vehicles		--	--	--

*Source: Reference 41.

**Based on cost estimates for 1972 dollars.

†Based on annual disposal volume of $250,000 m^3.

Use of an advanced shuttle configuration or a totally new low-cost HLLV could greatly reduce the launch cost. A conceptual vehicle capable of placing a 500,000 pound payload into LEO (the shuttle capacity is 65,000 pounds) for 5 million (1977) dollars, equivalent to about 9 dollars per pound, would yield a factor of 23.5 in cost reduction over the standard shuttle vehicle (Ref. 41). Applying this factor for LEO injection to the eight destinations listed in Table F-2 (not strictly accurate, but adequate for the purpose of this discussion) yields a rough minimum value for the cost per pound of space disposal based on advanced technology. For comparison with other LLW disposal methods, launch costs are also entered in Table F.2 in terms of the cost per cubic meter of waste (assuming an average waste density of 1.6 g/cm^3, or 3,500 lbs/m^3).

The amount of LLW expected to be generated in the U.S. between 1980 and 2000 is roughly 250,000 m^3/y averaged over the next 20 years. At a waste density of approximately 1,600 kg/m^3, this would equal 875 million pounds of waste to be disposed of per year. The annual launch costs would therefore range from 24 billion to 17 billion dollars. Also, at 500,000 pounds (143 m^3) per launch, this would require almost five HLLV launches per day.

The costs shown in Table F.2 do not account for cost-saving measures aimed at reducing the quantities of LLW to be launched (e.g., advanced radioisotope separation and concentration, increased hold-up time before launch, and exclusion of very low activity wastes. Hence, the total annual costs could undoubtedly be reduced. Conversely, the launch costs for the HLLV are based on a launch vehicle that currently exists only on paper. The estimated unit costs (per m^3) are based on the assumption that the entire payload is LLW. In actuality, the payload includes the waste container, which could be a large fraction of the payload for wastes requiring sustantial gamma shielding, or for protection against atmospheric burn-up following an aborted launch.

Although there is uncertainty in HLLV launch costs, they are sufficiently accurate for the purpose of comparing space disposal with other methods discussed in this report. For reference purposes, the estimated design and operation unit costs for land disposal range from \$185/m^3 (\$5.24/ft^3) for the reference near-surface disposal facility to \$839/m^3 (\$23.80/ft^3) for a mined cavity. The cost of the least expensive space disposal method (launch costs only) is thus seen to be three orders of magnitude greater than for land-based disposal. (As noted previously, this estimate is based on an advanced HLLV yet to be developed.) In conclusion, it can be seen that space disposal is not currently feasible economically or technically for LLW disposal. The development of a HLLV would render this option technically feasible, but it would still not be cost effective. However, space disposal remains of interest for the disposal of HLW.

5. COSTS

In this section, estimated costs for implementation of the disposal options considered in this appendix are presented. The cost analyses presented in this section are calculated based on the approach set out in Appendix Q and represent incremental cost changes from those calculated in Appendix Q for the reference disposal facility.

The cost analyses are broken down into (1) capital costs, and (2) operational costs. Postoperational costs for the optional disposal technologies or for various combinations of optional disposal technologies are generally considered as part of the analyses performed in Chapters 4 and 5 of the EIS. Unit costs for equipment and material were obtained from standard construction guides (e.g., Refs. 3, 42 and 43) and from information obtained from a consultant (the firm of Dames and Moore of White Plains, NY).

Additional capital costs are calculated based upon the postulated need to (1) purchase additional equipment and material during the preoperational period of the disposal facility, and (2) enlarge the size of disposal facility buildings to accommodate increases in the number of personnel and construction equipment, and the amount of material used during operations. In the disposal options, additional purchased equipment and material frequently consisted of monitoring equipment such as air samplers. (Additional air samples were assumed to be installed when a particular disposal option was likely to result in additional disposal cells under operation simultaneously or when a particular disposal option had a potential for release of airborne contamination.) Similar to Appendix Q, additional heavy construction equipment was not assumed to be purchased but was assumed to be leased during the operational period.

Costs for enlargement of disposal facility buildings for the disposal options were estimated through use of Table F.3. Each disposal option was assessed regarding three considerations: (1) the relative number of additional personnel required, (2) the relative number of additional construction equipment required and (3) the relative amount of additional perishable supplies required (i.e., supplies that would have to be protected from weather). For each consideration, a low, medium, or high level of increase was assigned. The sizes of the health physics building ($45/ft^2), garage (25/ft^2), and warehouse (25/ft^2) were then increased as follows:

	Building size increase (ft^2)		
Level of increase	Health physics (personnel)	Garage (equipment)	Warehouse (consumables & supplies)
Low	0	0	0
Medium	4,000	1,000	1,000
High	8,000	2,000	5,000

To assign the increase levels for the health physics building and garage, the following numerical guide was used:

Table F.3 Relative Level of Increase in Personnel, Equipment, and Storage for Disposal Options

Disposal Options	Relative # of Additional Personnel	Relative # of Additional Equipment	Relative Increase in Storage	Additional Construction
Deeper trench (no shore)	low	low	low	
Deeper trench (shoring)	mod	low	mod	
Increased distance	low	low	low	Additional lan
Thicker trench cover	low	low	low	
Layered waste disposal	low	low	low	1-storage bldg
Slit trench (10% of vol.)	low	low	low	
Caisson disposal (10% of vol.)	mod	mod	mod	
Concrete walled trench (10% of vol.)	mod	mod	mod	
Concrete walled trench (100% of vol.)	high	high	high	
Grouting	low	mod	mod	
Engineered intruder barrier	mod	high	mod	
Improved monitoring	low	low	low	
Improved thicker trench covers	low	low	low	
Moisture barriers	low	low	low	
Sand backfill	low	low	low	
Surface water drainage	low	low	mod	
Weather shielding	low	low	low	
Stacked emplacement	mod	mod	low	
Waste segregation	low	low	low	
Improved compaction	low	low	low	
Decontainerized disposal	high	mod	mod	1-storage bldg. + increase wast activities bldg
Dynamic compaction	low	low	low	

Level of increase	Health physics building (# of additional personnel)	Garage (# of additional pieces of equipment)
Low	0-10	0-3
Medium	11-30	4-9
High	31+	10+

To assign increase levels for the warehouse, a judgment was made considering the relative amount of material (e.g., cement) that would need to be purchased during operations as well as the relative number of additional personnel. For some disposal options, additional building space was required as shown in Table F.3. Additional operational costs are grouped into five main areas:

- o additional trench construction materials;
- o additional personnel;
- o additional consumables;
- o additional equipment; and
- o additional monitoring charges.

Additional trench construction materials include such items as standpipes, gravel, cornermarkers, cement, etc. Surveying charges (to bench mark disposal cells) were also included as part of materials costs. Surveying costs were estimated by assuming that the disposal facility operators subcontract with a surveyor as a consultant and that each disposal cell requires 8 hours at $60/hr. However, an upper limit on surveying charges was established at $120,000/yr. As the number of disposal cells to be surveyed increase, it will eventually be cheaper to retain a surveyor full time rather than as a part time consultant.

Personnel costs were estimated in the same manner as personnel costs in Appendix Q. A base level of costs are first estimated and then a ten percent fringe is calculated. A 50% overhead is then calculated from the sum of the base and the fringe costs. Finally, the base, fringe, and overhead costs are summed. Similarly to Appendix Q, costs for consumables were then estimated as 10% of the base personnel costs.

Additional heavy equipment costs were estimated by assuming that all such additional equipment is leased.

Additional monitoring charges were estimated by assuming a number of offsite analyses (e.g., gamma spectrum I-131) are performed at an average charge of $50 per sample analysis.

The cost analyses presented in this section for disposal options representing variations on near-surface disposal include the following:

Disposal Option	Table
Deeper trench	F.4
Thicker trench covers	F.5
Increased distance below top of trench	F.6
Layered waste disposal	F.7
Slit trench (10% of waste volume)	F.8
Caisson disposal (10% of waste volume)	F.9
Concrete walled trench (10% of waste volume)	F.10
Concrete Walled trench (entire waste volume)	F.11
Grouting	F.12
Engineered human intrusion barrier	F.13
Improved monitoring	F.14
Improved compaction	F.15
Improved thicker cap	F.16
Moisture barriers	F.17
Sand backfill	F.18
Surface water drainage system	F.19
Weather shielding	F.20
Stacked waste emplacement	F.21
Waste segregation	F.22
Decontainerized disposal	F.23
Dynamic compaction	F.24

Table F.4 Differential Costs for Deep Trench Disposal

Assumptions:

- Total volume input of 1 million m^3/20 years, or 50,000 m^3/year
- 30 deep trenches (approximate dimensions: 180 m x 30 m x 16m) replace 58 reference trenches
- Random disposal of waste
- Waste volume capacity of deeper trench = 33,600 m^3
- Costs are calculated with and without shoring

ADDITIONAL CAPITAL COSTS	
A. Without Shoring	$ 0
B. With Shoring	
(1) Increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	$180,000
(2) Increase warehouse by 10,000 ft^2 @ $42/$ft^2$	250,000
	$430,000
Engineering and Design:	43,000
	$473,000
ADDITIONAL OPERATIONAL COSTS	
A. Additional Trench Construction Materials	
(1) Standpipes and Casings	
58 reference trenches @ $670.50/trench	$ 38,889
30 deep trenches	
56 ft of 6" pvc standpipe @ $2.45/ft	
3 standpipes/trench = $411.60/trench	
3 standpipe casings @ $150/standpipe = $450/trench	
30 trenches @ $861.60/trench	$ 25,848
	-$ 13,041
(2) French Drain	
58 reference trenches @ $425/trench	$ 24,650
30 deep trenches @ $425/trench	$ 12,750
	-$ 11,900

Table F.4 (continued)

(3) Seed and Mulch		
1.5 acres/trench @ $295/acre		
58 reference trenches		$ 25,665
30 deep trenches		$ 13,275
		-$ 12,390
(4) Corner Markers and Monuments		
6.7 ft² of granite corner markers and monuments per trench @ $18.30/ft² = $122/trench		
58 reference trenches		$ 7,076
30 deep trenches		$ 3,662
		-$ 3,414
(5) Surveyor		
$60/hr and 8 hrs/trench		
58 reference trenches		$ 27,840
30 deep trenches		$ 14,400
		-$ 13,440
(6) Shoring (optional)		
58 reference trenches		$ 0
30 deep trenches		
wall area/trench = 6720 m² = 72,334 ft²		
material charge = $2.40/ft²		
30 trenches x 72,334 ft² x $2.40		$5,208,050
		+ $5,208,050
B. Additional Personnel		
(1) With No Shoring		
1 heavy equipment operator @ $21,000		$ 21,000
	Fringe:	2,100
	Overhead:	$ 11,550
		$ 34,650
	x 20 yrs	$ 693,000
(2) With Shoring		
1 heavy equipment operator @ 21,000		21,000
5 semiskilled laborers @ $15,000		75,000
10 unskilled laborers @$10,000		100,000
		$ 196,000
	Fringe:	19,600
	Overhead:	107,800
		$ 323,400
	x 20 yrs	$6,468,000

Table F.4 (continued)

C.	Additional Consumables	
	With no shoring	$ 42,000
	With shoring	$ 392,000
D.	Additional Equipment	
	1 - drag-line excavator for 240 months @ $8,000/mo	$ 1,920,000
E.	Additional Monitoring	0
	Total additional operational charges	
	With shoring:	$13,933,865
	Without shoring:	$ 2,555,807

Unit Differential Costs:

With shoring: $\frac{10.38(473,000)+1.56(13,933,865)}{1,000,000\ m^3} = \frac{26,646,569/m^3}{1,000,000}$

$= \$26.65/m^3\ (\$0.75/ft^3)$

Without shoring: $\frac{1.56(2,555,807)}{1,000,000\ m^3} = \$3.99/m^3\ (\$0.11/ft^3)$

Table F.5 Differential Costs for Thicker Trench Covers

Assumptions:

- Costs are estimated based upon the equivalent construction costs of \$0.75/yd^3 to excavate, haul, and spread earth using scrapers at an average haul distance of 1,500 ft and an average rate of 5,500 yd^3/day
- Fill required = disposal area x cover thickness, where the disposal area = vol/(EMP x EFF x SEFF), Vol = waste volume (m^3); EMP = emplacement efficiency; EFF = volumetric disposal efficiency (m^3/m^2); SEFF = surface use efficiency
- Example calculations are developed for Vol = 1,000,000 m^3; EMP = 0.5 (random disposal); EFF= 6.4 m^3/m^2 (reference trench); SEFF = 0.9 (reference trench); and a cover thickness = 3m.

ADDITIONAL CAPITAL COSTS	\$ 0
ADDITIONAL OPERATIONAL COSTS	
Excavation, haul, and spread of fill volume required = 1,000,000/(.5 x 6.4 x .9) = 347,222 m^3/m^2 of cover 3 meters cover: 1,041,667 m^3 = 1,362,500 yd^3	
Costs = 1,362,500 yd^3 @ \$0.75/yd^3	\$1,021,875
Total additional operational costs	\$1,021,875

Unit Differential costs

$$\frac{1.56(1,021,875)}{1,000,000} = \frac{1,594,125}{1,000,000} = \$1.59/m^3\ (\$0.05/ft^3)$$

Costs per unit disposal area = \$0.55/m^2

Table F.6 Differential Costs for Increasing the Distance Between the Waste and the Top of the Disposal Cell

---

Assumptions:

- Costs are calculated on the basis of 1,000,000 m^3 of waste randomly disposed into reference disposal trenches.
- The bottom 4 m (rather than the bottom 7 meters) is used for waste disposal, resulting in a reduction in trench waste capacity (50% disposal efficiency) from about 17,230 m^3 to about 9,524 m^3. The number of trenches required is increased from 58 to 105, and the number of disposal trenches that need to be constructed per year is raised from about 3 to 5-6.
- The land area commited for disposal is raised from about 87 acres to about 157 acres, or an additional 70 acres.
- Additional costs involve additional material costs such as standpipes and markers, as well as additional land. Also, since the number of trenches that must be excavated is increased, additional machinery and personnel are assumed to be required.

ADDITIONAL CAPITAL COSTS

Purchase 40 additional acres of land @ $1200/acre	$ 48,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials

1. Standpipes and Casing	
58 reference trenches @ $670.50/trench	$ 38,889
105 reference trenches @ 670.50/trench	70,403
	+ $ 31,514
2. Gravel Drain	
58 reference trenches @ $425/trench	$ 24,650
105 reference trenches @ $425/trench	44,625
	+ $ 19,975
3. Seed and Mulch	
87 acres @ $295/acre	$ 25,665
157 acres @ $295/acre	46,315
	+ $ 20,650

Table F.6 (Continued)

4.	Corner markers and monuments		
	58 reference trenches @ $122/trench		$ 7,076
	105 reference trenches @ $122/trench		12,810
			+ $ 5,734
5.	Surveyor		
	58 reference trenches @ $480/trench		$ 27,840
	105 reference trenches @ $480/trench		50,400
			+ $ 22,560
B.	Additional Personnel		
	1-heavy equipment operator @ $21,000		$ 21,000
		Fringe:	2,100
		Overhead:	11,550
		x 20 yr	$ 693,000
C.	Additional Consumables		$ 42,000
D.	Additional Equipment		
	1 - panscraper for 24 mo. @ $8,000/mo		$ 1,920,000
E.	Additional Monitoring		0
	Total additional operational costs		$ 2,713,433

Unit Differential Costs

$$\frac{10.38\ (48{,}000) + 1.56\ (2{,}713{,}433)}{1{,}000{,}000} = \frac{4{,}731{,}194}{1{,}000{,}000}$$

$$= \$4.73/m^3\ (0.13/ft^3)$$

Table F.7 Differential Costs for Layering Operations

Assumptions:

- 10% of the one million m^3 (100,000 m^3) requires layering
- Layering requires a waste storage building and additional labor

ADDITIONAL CAPITOL COSTS

Building Construction-add 6,000 ft^2 storage building @ \$20/ft^2		\$ 120,000
	Engineering and Design	\$ 12,000
		\$ 132,000

ADDITIONAL OPERATIONAL COSTS

A.	Additional Trench Construction Materials		\$ 0
B.	Additional Personnel		
	1 Radiation safety technician @\$15,000		\$ 15,000
	1 Semiskilled laborer @ \$15,000		\$ 15,000
	1 Quality assurance technician @\$14,000		\$ 14,000
			\$ 44,000
		Fringe:	\$ 4,400
		Overhead:	\$ 24,200
			72,600
		x 20 yrs	\$1,452,000
C.	Additional Consumables		\$ 88,000
D.	Additional Equipment		0
E.	Additional monitoring		0
	Total additional operational costs:		\$1,540,000

Unit differential costs (per m^3 of layered waste)

$$\frac{10.38(132,000) + 1.56(1,540,000)}{100,000} = \frac{1,370,160 + 2,402,400}{100,000}$$

$$= \frac{3,772,560}{100,000} = \$37.73/m^3 \ (\$1.07/ft^3)$$

Table F.8 Differential Costs for Slit Trench Operations (Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in slit trenches, which replace an equivalent volume of randomly disposed waste in reference trenches.
- Slit trench dimensions: 20m x 3m x 8m, of which the bottom 7m is used for waste disposal. Spacing between trenches = 2m. Disposal efficiency = 50%.
- Slit trench waste capacity = 210 m^3, reference trench waste capacity = 17,230 m^3. Therefore, 492 slit trenches (disposal volume = 100,320 m^3) replace 6 reference trenches.
- Unit area of slit trench = (22m x 5m) = 110m^2 = 1184 ft^2. Surface area of 492 slit trenches = 582,528 ft^2. Surface area of 6 reference trenches = 6 x (183m x 33m) = 36,234 m^2 = 390,057 ft^2 = 8.95 acres.
- Use of slit trenches for 10% of waste requires additional 517,518 ft^2 = 11.88 acres. Existing licensed acreage sufficient.
- Construct approximately 25 trenches/yr, or one every 2 weeks
- Assume deletion of standpipe and gravel drain. Emplacement would otherwise require trench shoring at considerable additional expense.

ADDITIONAL CAPITAL COSTS

Add atmospheric sampler @ $900	$	900
Engineering and Design		90
	$	990

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

(1) Standpipes

6 reference trenches @ $670.50/trench	$	4,023
492 slit trenches assume no stand pipes		0
	–$	4,023

(2) French Drain

6 reference trenches @ $425/trench	$	2,550
492 slit trenches assume no installed drain		0
	–$	2,550

(3) Seed and mulch

6 reference trenches x 1.5 acres/trench x $295/acre	$	2,655
492 slit trenches require 12 acres		
12 acres x $295/acre		3,540
	+$	885

Table F.8 (continued)

(4) Corner Markers and Monuments		
6.7 ft^2 of granite corner markers and monuments per trench @ \$18.30/ft^2		
6 reference trenches		\$ 732
492 slit trenches		60,054
		+\$ 59,322
(5) Surveyor		
\$60/hr and 8 hrs/trench		
6 reference trenches		\$ 2,880
492 slit trenches		236,160
		+\$ 233,280
B. Additional Personnel		
1-heavy equipment operator @ \$21,000		\$ 21,000
2-semiskilled laborers @ \$15,000		30,000
2-unskilled laborers @ \$10,000		20,000
1-radiation safety technician @ \$15,000		15,000
1-quality assurance technician @ \$14,000		14,000
		\$ 100,000
	Fringe:	10,000
	Overhead:	55,000
		\$ 165,000
	x 20 yrs	\$3,300,000
C. Additional Consumables		\$ 200,000
D. Additional Equipment		
1-backhoe for 240 mo @ \$4,000/mo		960,000
1-40 ton crane for 240 mo @ \$4,500/mo		1,080,000
		\$2,040,000
E. Additional Monitoring		
50 offsite sample analyses/yr @ average \$50/sample x 20 years		\$ 50,000
Total additional operational costs		\$5,876,914

Unit differential costs

$$\frac{10.38(990) + 1.56(5,876,914)}{100,320} = \frac{9,178,262}{100,320} = \$91.49/m^3 = \$2.59/ft^3$$

Table F.9 Differential Costs for Caisson Disposal (Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in caissons, which replace an equivalent volume of randomly disposed waste in reference trenches
- Assume caissons consist of 30" concrete culvert pipes 24 ft in length, placed in slit trenches constructed 15m x 1.5m x 8m, 16 caissons per trench. Average spacing between trench = 1m.
- Assume deletion of standpipes and gravel drain. Emplacement would otherwise require trench shoring at considerable additional expense.
- Disposal capacity is $40m^3$/trench, assuming stacked disposal at 75% efficiency. Reference trench waste capacity = $17,230m^3$. Therefore, 2,585 caisson trenches (disposal volume = 103,400) replace 6 reference trenches.
- Unit area of caisson trench = (16m x 2.5m) = 40 m^2 = 430.6 ft^2. Surface area of 2,585 caisson trenches = 1,113,100 ft^2. Surface area of 6 reference trenches = 390,060 ft^2
- Use of slit trenches for 10% of waste requires additional 723,040 ft^2 = 16.6 acres
- Construct approximately 129 caisson trenches, or 2.5/week.
- After waste placement, backfill with concrete (0.6 m thick concrete cap) plus overburden.

ADDITIONAL CAPITAL COSTS

(1)	3-atmospheric samplers @ $900 each	$ 2,700
(2)	increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	180,000
(3)	increase garage by 1000 ft^2 @ $25/$ft^2$	25,000
(4)	increase warehouse by 1000 ft^2 @$25/$ft^2$	25,000
		$ 232,700
	Engineering and Design:	23,270
		$ 255,970

ADDITIONAL OPERATIONAL COSTS

A. Additional Construction Materials

(1) Standpipes

6 reference trenches @ $670.50/trench	$ 4,023
2585 caisson trenches assume no standpipes	0
	-$ 4,023

Table F.9 (continued)

(2) French Drain	
6 reference trenches @ $425/trench	$ 2,550
2,585 caisson trenches assume no gravel required	0
	-$ 2,550
(3) Seed and Mulch	
6 reference trenches x 1.5 acres/trench x $295/acre	$ 2,655
2,585 caisson trenches require 24 acres	
24 acres x $295/acre	7,080
	+$ 4,425
(4) Corner Markers and Monuments	
6 reference trenches @ $122/trench	$ 732
2,585 caisson trenches @ $122/trench	315,528
	+$ 314,796
(5) Surveyor	
6 reference trenches @ $480/trench	$ 2,880
Surveyor consulting fees @ $120,000/yr	240,000
	+$ 237,120
(6) Concrete Backfill (cap)	
fill/trench = (15m x 1.5m x 0.6m) = 13.50 m^3 = 17.7 yd^3	
17.7 yd^3 @ $45/$yd^3$ x 2,585 trenches	+$2,054,067
B. Additional Personnel	
2-heavy equipment operators @ 21,000	$ 42,000
4-semiskilled laborers @ 15,000	60,000
2-unskilled laborers @ 10,000 =	20,000
2-radiation safety technicians @ 15,000 =	30,000
1-quality assurance technician @ $14,000 =	14,000
	$ 166,000
Fringe:	16,600
Overhead:	91,300
	$ 273,900
x 20 yrs	$5,478,000
C. Additional Consumables	$ 332,000

Table F.9 (continued)

D.	Additional Equipment	
	2-backhoes for 240 mo @ $4,000/mo	$ 1,920,000
	2-40 ton cranes for 240 mo @ $4500/mo	2,160,000
		+$ 4,080,000
E.	Additional Monitoring	
	150 offsite sample analyses/yr @ average $50/sample x 20 years	$ 150,000
	Total additional operational costs	$12,643,835

Unit Differential Costs

$$\frac{10.38\ (255{,}970) + 1.56\ (12{,}643{,}835)}{103{,}400} = \frac{\$22{,}381{,}351}{103{,}400}$$

$$= \$216.45/m^3\ (\$6.13/ft^3)$$

Table F.10 Differential Costs for Concrete Walled Trench (Ten Percent of Waste Volume)

Assumptions:

- About ten percent of 1,000,000 m^3 of waste is disposed in walled trenches, which replace an equivalent volume of waste randomly disposed in reference trenches
- Walled trench inside dimensions: 12 m x 3 m x 8.3 m, of which the bottom 7.3 m is used for waste disposal. The thickness of walls and slab = 0.3 m. A 0.3 m-thick gravel base is placed on the bottom of the trench. Spacing between trenches = 3 m. Disposal efficiency = 75% (stacked disposal).
- Concrete walled trench waste capacity = 189 m^3; reference trench waste capacity = 17,230 m^3. Therefore, 547 walled trenches replace 6 reference trenches (disposal volume = 103,400 m^3).
- Unit area of walled trench = (15.3 m x 6.3 m) = 96.4 m^2 = 1,038 ft^2. Surface area of 6 reference trenches = 390,060 ft^2 = 9 acres. Surface area of 547 walled trenches = 567,645 ft^2 = 13 acres.
- Use of concrete walled trenches for 10% of waste requires an additional 177,585 ft^2 = 4 acres
- Construct approximately 27 walled trenches/yr or about one every two weeks.

ADDITIONAL CAPITAL COSTS

(1)	add 1 atmospheric sampler @ $900	$ 900
(2)	increase health physic/security building by 4,000 ft^2 @ $45/$ft^2$	180,000
(3)	increase garage by 1,000 ft^2 @ $25/$ft^2$	25,000
(4)	increase warehouse by 1,000 ft^2 @$25/$ft^2$	25,000
		$ 230,900
	Design and Engineering:	23,090
		$ 253,990

ADDITIONAL OPERATIONAL COSTS

A. Additional Construction Materials

(1) Standpipes and Casings

6 reference trenches @ $670.50/trench	$ 4,023
547 walled trenches with one standpipe/trench	
547 trenches @ $223.50/trench	$ 122,255
	+$ 118,232

Table F.10 (continued)

(2)	Gravel Drain	
	reference trenches @ \$425/trench	\$ 2,550
	547 walled trenches. Gravel volume/trench = (12m x 3m x 1.3m) = 10.8 m^3 = 14.13 yd^3	
	547 trenches x 14.13 yd^3/trench x \$5/yd^3	\$ 38,636
		+ \$ 36,086
(3)	Seed and Mulch	
	6 reference trenches x 1.5 acres/trench x \$295/acre	\$ 2,655
	547 walled trenches require 13 acres	
	13 acres @ \$295/acre	\$ 2,835
		+\$ 1,180
(4)	Corner Marker and Monuments	
	6 reference trenches @ \$122/trench	\$ 732
	547 walled trenches @ \$122/trench	\$ 66,734
		+\$ 66,002
(5)	Surveyor	
	6 reference trenches \$\$480/trench	\$ 2,880
	Surveyor consulting fees	\$ 240,000
		+\$ 237,120
(6)	Additional Material	
	Form work	
	30 m x 8.6m 258m^2 = 2777 ft^2/trench. Form work = \$0.68/ft^2 for 3 uses prior to replacement	
	2777 ft^2/trench x 547 trenches x \$0.68/ft^2	\$1,032,933
	Concrete	
	124.2m^3/trench = 162.45 yd^3 x 547 trenches @ \$45/yd^3	\$3,998,795
	Reinforcing Steel	
	0.74 tons/trench x 547 trenches @ \$430/ton	\$ 174,055

B. Additional Personnel

4-semiskilled laborers @ 15,000		\$ 60,000
4-unskilled laborers @ \$10,000		40,000
1-heavy equipment operator @ \$21,000		21,000
1-radiation safety technician @ \$15,000		15,000
1-quality assurance technician @ \$14,000		14,000
		\$ 150,000
	Fringe:	\$ 15,000
	Overhead:	82,500
		247,500
	x 20 yrs	\$4,950,000

Table F.10 (continued)

C.	Additional Consumables	$ 300,000
D.	Additional Equipment	
	2-40 ton cranes for 240 mo @ $4,500/mo	$ 2,160,000
	1-concrete pump for 240 mo @ $5,000/mo	1,200,000
	1-backhoe for 240 mo @ $4,000/mo	960,000
		$ 4,320,000
E.	Additional Monitoring	
	50 offsite sample analyses/yr @ average $50/sample x 20 yrs	$ 50,000
	Total additional operational costs	$15,284,403

Unit Differential Costs

$$\frac{10.38\ (253{,}990) + 1.56(15{,}284{,}403)}{103{,}400} = \frac{26{,}480{,}085}{103{,}400}$$

$$= \$256.09\ m^3\ (\$7.25/ft^3)$$

Table F.11 Differential Costs for Concrete Walled Trench (Entire Waste Volume)

Assumptions:

- o Disposal of 1,000,000 m^3 of waste entirely in walled trenches.
- o Walled trench capacity = 189 m^3, requires 5,291 trenches.
- o Surface area of 5,291 trenches = 5,492,000 ft^2 = 126.08 acres. Surface area of 58 reference trenches = 3,770,000 ft^2 = 87 acres. Use of walled trenches requires additional 39.5 acres.
- o Construct 265 trenches/yr or about 5 trenches/week.

ADDITIONAL CAPITAL COSTS

(1)	Add five atmospheric samplers @ $900	$ 4,500
(2)	Increase health physics/security building by 8,000 ft^2 @ $45/$ft^2$	360,000
(3)	Increase garage by 2,000 ft^2 @ 25/ft^2	50,000
(4)	Increase warehouse by 5,000 ft^2 @ $25/$ft^2$	$ 125,000
		539,500
	Engineering and Design:	53,950
		$ 593,450

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Constructional Materials

(1) Standpipes and Casings

58 reference trenches @ $670.50/trench	$ 38,889
5,291 walled trenches with one standpipe/trench 5,291 trenches @ $223.50/trench	$1,182,539
	+$1,143,650

(2) Gravel Drain

58 reference trenches @ $425/trench	$ 24,650
5,291 walled trenches. 5,291 trenches x 14.13 yd^3/trench x $5/$yd^3$	$ 373,809
	+$ 349,159

(3) Seed and Mulch

58 reference trenches x 1.5 acres/trench @ $295/acre	$ 25,665
5,291 walled trenches 126 acres @ $295/acre	$ 37,170
	+$ 11,505

Table F.11 (continued)

(4) Corner Markers and Monuments

58 reference trenches @ $122/trench	$ 7,076
5,291 walled trenches @ $122/trench	$ 645,502
	+$ 638,426

(5) Surveyor

58 reference trenches @ $480/trench	$ 27,840
Surveying consultant costs @ $120,000/yr	$ 2,400,000
	+$ 2,372,160

(6) Additional Material

Formwork - 2777 ft^2/trench x 5291 trenches @ $0.68/$ft^2$	$ 9,991,313
Concrete - 162.45 yd^3/trench x 5291 trenches @ $45/$yd^3$	$38,678,533
Reinforcing Steel - 0.74 tons/trench x 5291 trenches @ $430/ton	$ 1,683,596

B. Additional Personnel

3-radiation safety technicians @ $15,000 =		$ 45,000
30-semiskilled laborers @ $15,000		450,000
30-unskilled laborers @ $10,000		300,000
3-heavy equipment operators @ $21,000		63,000
3-quality assurance technicans @ $14,000		42,000
1-foreman @ $28,000		28,000
		$ 928,000
	Fringe:	92,800
	Overhead:	$ 510,400
		$ 1,531,200
	x 20 yrs	$30,624,000

C. Additional Consumables — $ 1,856,000

D. Additional Equipment

4-concrete pumps 240 mo @ $5,000/mo	$ 4,800,000
3-backhoes for 240 mo @ $4,000/mo	2,880,000
3-40 ton cranes for 200 mo @ $4,500/mo	3,240,000
3-pickup trucks for 240 mo @ $750/mo	540,000
1-farm tractor for 240 mo @ $800/mo	192,000
	$11,652,000

Table F.11 (continued)

E. Additional Monitoring	
200 offsite sample analyses/yr @ average $50/sample x 20 yrs.	$ 250,000
Total additional operational costs:	$99,250,342

Unit Differential Costs

$$\frac{10.38(593,450) + 1.56\ (99,250,342)}{1,000,000} = \frac{160,990,545}{1,000,000}$$

$$= 160.99/m^3\ (4.56/ft^3)$$

Table F.12 Differential Costs for Grouting

Assumption:

- Costs based upon 1,000,000 m^3 of waste disposed by stacking into reference trenches. (75% efficiency). Available disposal volume per trench = 2 x 17,230 m^3 = 34,460 m^3. At 75% efficiency, have 25,845 m^3 of waste and 8,615 m^3 of void space per trench (not counting 1 m backfill between top of waste and trench). Disposal of 1,000,000 m^3 of waste by stacking therefore requires 1E+6/25,845 = 39 trenches having 333,000 m^3 of void space. Grout volume therefore equals waste volume x $\frac{(1-EFF)}{EFF}$
- Differential costs for stacking included elsewhere (see Table F.21). Costs are for grouting alone.
- Case A: cement
  Case B: low strength (200 psi) cement)

ADDITIONAL CAPITAL COSTS

(1) Increase garage by 1,000 ft^2 @ \$25/ft^2		\$ 25,000
(2) Increase warehouse by 1,000 ft^2 @ \$25/ft^2		25,000
		\$ 50,000
	Engineering and Design:	5,000
		\$ 55,000

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

(1) Grout		
Case A.	333,000 m^3 = 436,000 yd^3 @ \$45/yd^3	\$19,619,980
Case B.	436,000 yd^3 @ \$25/yd^3	\$10,900,000

B. Additional Personnel

1-semiskilled laborer @ \$15,000		\$ 15,000
2-unskilled laborers @ \$10,000		20,000
1-quality assurance technician @ \$14,000		14,000
		\$ 49,000
	Fringe:	4,900
	Overhead:	26,950
		\$ 80,850
	x 20 yrs	\$ 1,617,000

C. Additional Consumables — \$ 98,000

Table F. 12 (continued)

D. Additional Equipment

2-cement pumps for 240 mo @ $5,000/mo	$ 2,400,000
2-tremie pipe and hose systems	400,000
	$ 2,800,000

E. Additional Monitoring — $ 0

Total additional operational costs

Case A	$24,134,980
Case B	$15,415,000

Unit Differential Costs

Case A. Cement:

$$\frac{10.38(55{,}000) + 1.56\,(24{,}134{,}980)}{1{,}000{,}000} = \frac{38{,}221{,}469}{1{,}000{,}000}$$

$$= \$38.22/m^3 \ (\$1.08/ft^3)$$

$$= \$114.66/m^3 \text{ of grout}$$

Case B. Low-Strength Cement:

$$\frac{10.38(55{,}000) + 1.56\,(15{,}415{,}000)}{1{,}000{,}000} = \frac{24{,}618{,}300}{1{,}000{,}000}$$

$$= \$24.62/m^3 \ (\$0.70/ft^3)$$

$$= \$73.85/m^3 \text{ of grout}$$

Table F.13 Differential Costs for Installation of an Engineered Human Intruder Barrier

---

Assumptions:

- o Costs based upon 1,000,000 m^3 of waste randomly disposed into reference trenches. This results in a total disposal area = vol/(EMP X EFF X SEFF) = 347,000 m^2, where EMP = 0.5, EFF = 6.4, and SEFF = 0.9.
- o The engineered intruder barrier is 5.5 m thick and consists of layers of sand, clay, gravel, cobbles, bounders asphaltic concrete, and topsoil, and is installed on top of existing 1 m thick backfill and 1 m thick cap.
- o The engineered intruder barrier consists of 43,511 yd^3 of material per trench at an average cost of $6.00/$yd^3$

CAPITAL COSTS:

Increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	$ 180,000
Increase garage by 2,000 ft^2 @ $25/$ft^2$	50,000
Increase warehouse by 1000 ft^2 @ $25/$ft^2$	25,000
	$ 255,000
Engineering and Design:	25,500
	$ 280,500

OPERATIONAL COSTS

A. Additional Materials

(1) Standpipes add 20 ft to each standpipe. 58 trenches x 3 standpipes/trench x 20 ft @ $2.45/ft	$ 8,526
(2) Barrier material 43,511 yd^3/trench x 58 trenches @ $6/$yd^3$	$15,141,828

B. Additional Personnel

4-heavy equipment operators @ 21,000/yr	$ 84,000
4-semiskilled laborers @ $15,000/yr	60,000
2-unskilled laborers @ $10,000/yr	20,000
2-quality assurance technicians @ $14,000	28,000
	$ 192,000
Fringe:	19,200
Overhead:	105,600
	$316,800
x 20 yrs	$ 6,336,000

Table F.13 (Continued)

C.	Consumables	$ 384,000
D.	Additional Equipment	
	2-pan scrapers for 240 months @ $8,000/mo	$ 3,840,000
	1-asphalt paver for 240 months @ $3,775/mo	906,000
	1-crawler tractor for 240 months @ $4,200/mo	1,008,000
	1-vibratory compactor for 240 months @ $6,000/mo	468,000
	5-dump trucks for 240 months @ $6,000/mo	7,200,000
	1-motor grader for 240 months @ $3,200/mo	768,000
		$14,190,000
E.	Additional Monitoring	0
	Total additional operational costs	$36,060,354

Unit Differential Costs

$$\frac{10.38(280,500) + 1.56(36,060,354)}{1,000,000} = \frac{59,165,742}{1,000,000}$$

$$= \$59.17/m^3 \ (\$1.68/ft^3)$$

Table F.14 Differential Costs for Improved Monitoring

Assumptions:

- Improved monitoring consists of 25 additional wells at an average depth of 60 ft, 10 particulate air samplers, and (optional) one automatic runoff sampler.
- Well construction: 1,500 total feet at $15/ft = $22,500.
- Cost of consulting services for well location selection = $20,000.
- Purchase and installation of 10 particulate air samplers @ $900/sampler = $9,000.
- Purchase and installation of automatic runoff sampler = $7,000.
- Construction of WEIR for sampler = $10,000.

CAPITAL COSTS			
Monitoring systems purchase and installation		$	48,500
Engineering and design fees			4,850
Consulting fees			20,000
		$	73,350
Without runoff sampler		$	54,650
OPERATIONAL COSTS			
A. Additional Trench Construction Materials			0
B. Additional Personnel			
1-radiation safety technician @ $15,000		$	15,000
	Fringe:		1,500
	Overhead:		8,250
			24,750
	x 20 yrs	$	495,000
C. Additional Consumables			30,000
D. Additional Equipment			0
E. Additional Monitoring			
Offsite sample analysis @ average $50/sample			
25 wells, quarterly samples			5,000
10 air samples, 50 each/yr			25,000
runoff samples, 50/yr			2,500
		$	32,500
	x 20 yrs	$	650,000
Total additional operational costs:		$	704,750
Without runoff samples		$	654,750

Table F.14 (continued)

Unit Differential Costs:

$$\frac{10.38(73,350) + 1.56(704,750)}{1,000,000} = \frac{1,860,783}{1,000,000}$$

$$= \$1.86/m^3 = \$0.05/ft^3$$

Without runoff samples: $1.59/m^3 = \$0.04/ft^3$

Table F.15 Differential Costs for Improved Compaction

Assumptions:

- o The costs are a function of the area compacted, which is Vol/(EMP x EFF x SEFF). Costs are estimated based upon 1,000,000 m^3 of randomly disposed waste, where EMP = 0.5, EFF = 6.4 m, and SEFF = 0.9.

ADDITIONAL CAPITAL COSTS		$	0
ADDITIONAL OPERATIONAL COSTS			
A. Additional Materials		$	0
B. Additional personnel			
1-heavy equipment operator @ $21,000		$	21,000
	Fringe:	$	2,100
	Overhead:	$	11,550
		$	34,650
	x 20 yrs	$	693,000
C. Additional Consumables		$	42,000
D. Additional Equipment			
1-vibratory compactor for 240 mo @ $1,950/mo		$	468,000
E. Additional Monitoring			0
Total additional operational costs			$1,203,000

Unit Differential Costs:

$$\frac{1.56(1,203,000)}{1,000,000} = \$1.88/m^3 \ (\$0.05/ft^3)$$

Cost per unit disposal area = $.065/$m^2$

Table F.16 Differential Costs for Improved Thicker Cap

Assumptions:

- Thicker Cap Case A. Two meters of imported clay compacted to 95% of maximum density.
- Thicker Cap Case B. Three meters of imported clay compacted to 95% of maximum density.
- Fill required = disposal area x cover thickness, where the disposal area = Vol/(EMP x EFFx SEFF), and
  - Vol = waste volume (m^3)
  - EMP = emplacement efficiency
  - EFF = volumetric disposal efficiency (m^3/m^2)
  - SEFF = surface use efficiency
- Example calculation for vol = 1 million m^3, EMP = 0.5 (random disposal), EFF = 6.4 m^3/m^2 (reference trench), and SEFF = 0.9 (reference trench)

ADDITIONAL CAPITAL COSTS $ 0

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials

Case A: 2 meter cap
disposal area = 1,000,000/(.5 x 6.4 x .9) = 347,222 m^2. Fill required = 694,444 m^3 = 908,333 yd^3
Purchase and haul fill @ $3.50/$yd^3$ — $ 3,179,165

Case B: 3 meter cap
fill required = 1,041,666m^3 = 1,362,499 yd^3
Purchase and haul fill @ $3.50/$yd^3$ — $ 4,768,747

B. Additional Personnel

1-heavy equipment operator @ $21,000		$ 21,000
	Fringe:	$ 2,100
	Overhead:	11,550
		$ 34,650
	x 20	$ 693,000

C. Additional Consumables — $ 42,000

D. Additional Equipment

1-crawler tractor for 240 mo @ $4200/mo	$ 1,008,000
1-vibratory compactor for 240 mo @ $1950/mo	$ 468,000
	$ 1,476,000

Table F. 16 (continued)

E.	Additional Monitoring	$ 0
	Total additional operational costs:	
	Case A:	$ 5,390,165
	Case B:	$ 6,979,747

Unit Differential Costs:

Case A: $\frac{1.56(5,390,165)}{1,000,000}$ = \$8.41/m^3 (\$0.24/ft^3)

= \$2.92/m^3 of disposal area

Case B: $\frac{1.56(6,979,747)}{1,000,000}$ = \$10.89/m^3 (\$0.31/ft^3)

= \$3.78/m^2 of disposal area

Table F.17 Differential Costs for Moisture Barriers

Assumptions:

- o Costs based upon random disposal of 1,000,000 m^3 of waste into 58 reference disposal trenches.
- o Barrier options: A = one bentonite layer
  B = one polymer membrane layer
  C = one polymer membrane layer plus one bentonite layer
  D = two polymer membrane layers
- o Bentonite is used as a rate of 4 lbs/ft^2
- o Costs in addition to those for 2 m-thick compacted clay caps (Table F.16).

ADDITIONAL CAPITAL COSTS		$ 0
ADDITIONAL OPERATIONAL COSTS		
A. Additional Trench Construction Materials		
Two meter thick clay cap (from Table F.16)		$ 3,179,165
Case A	86 acres (3,746,160 ft^2) of bentonite 7,492 tons @ $260/ton	$ 1,948,003
Case B	3,746,160 ft^2 of 36 mil reinforced hypalon @ $0.60/$ft^2$	$ 2,247,696
Case C	Material Cost of Case A plus Case B.	$ 4,195,699
Case D	Twice additional material cost of Case B.	$ 4,495,392
B. Additional Personnel		
1-heavy equipment operator @ $21,000		$ 21,000
	Fringe:	2,100
	Overhead:	11,550
		$ 34,650
	x 20	$ 693,000
C. Additional Consumables		$ 42,000
D. Additional Equipment		
1-crawler tractor for $240 mo @ $4200/mo		$ 1,008,000
1-vibratory compactor for $240 mo @ $1950/mo		$ 468,000
		$ 1,476,000

Table F.17 (Continued)

E. Additional Monitoring		$ 0
Total additional operational costs:		
	Case A:	$ 7,338,168
	Case B:	$ 7,637,861
	Case C:	$ 9.585.864
	Case D:	$ 9,885,557

Unit Differential Costs

Case A $\frac{1.56(7,338,168)}{1,000,000}$ = $11.45/m³ ($0.32/ft³)

Case B $\frac{1.56(7,637,861)}{1,000,000}$ = $11.92/m³ ($0.34/ft³)

Case C $\frac{1.56(9,585,864)}{1,000,000}$ = $14.95/m³ ($0.42/ft³)

Case D $\frac{1.56(9,885,557)}{1,000,000}$ = $15.42/m³ ($0.44/ft³)

Table F.18 Differential Costs for Use of a Sand Backfill

Assumptions:

- Costs estimated based upon disposal of 1,000,000 m^3 of waste into reference disposal trenches.
- Sand backfill is assumed to be procured, trucked to the disposal facility, and stockpiled for use at an average cost of $2.50/yd³.
- Costs are calculated for both random and stacked disposal, and include an equivalent of a 1 m thick backfill between the waste and the top of the trench. For random disposal, required sand volume = 1,000,000 m^3 + 58 x (180 m x 30 m x 1 m) = 1,313,200 m^3. For stacked disposal, required sand volume = 333,333 m^3 + 39 x (180 m x 30 m x 1m) = 543,933 m^3.

ADDITIONAL CAPITAL COSTS	$ 0
ADDITIONAL OPERATIONAL COSTS	
A. Additional Materials	
Random disposal	
1,313,200 m^3 = 1,717,666 yd^3 @ $2.50/yd³	$ 4,294,164
Stacked disposal	
543,933 m^3 = 711,464 yd^3 @ $2.50/yd³	$ 1,778,661
B. Additional Personnel	$ 0
C. Additional Consumables	$ 0
D. Additional Equipment	$ 0
E. Additional Monitoring	$ 0
Total additional operational costs:	
random disposal	$ 4,294,164
stacked disposal	$ 1,778,661

Unit Differential Costs

Random disposal: $\frac{1.56\ (4,294,164)}{1,000,000}$ = $6.70/m³ ($0.19/ft³)

Stacked disposal: $\frac{1.56\ (1,778,661)}{1,000,000}$ = $2.77/m³ ($0.08/ft³)

Cost per m^3 of sand = 5.11/m³ ($0.14/ft³)

Table F.19 Differential Costs for a Surface Water Drainage System

---

Assumptions:

- Primary system, discharge channel, and run-off monitor installed during facility construction, secondary system installed in stages during facility operations.
- Primary system runs entirely around 60 ha state-owned land plus along 2 north-south site access roads. (See Figure E.11) (system 5200 m in total length)
- Secondary system runs between trenches (along lengths and ends) and carries discharge to primary system (system 10,900 m in total length).
- Drainage channel carries discharge from primary system to an offsite publicly owned drainage channel which empties into a nearby stream.
- Primary system consists of 1/3 section of 24" radius galvanized pipe; secondary system consists of 1/3 section of 15" radius galvanized pipe; discharge channel consists of trapezoidal sectioned gravel channel 500 m long. Gravel layer 3.5 m wide and 0.6 in thick.

CAPITAL COSTS

(1)	Primary system: 5200 m = 17,061 ft @ $19.43 ft	$ 331,499
(2)	Discharge channel: gravel (3.5 m x 500m) = 1050m^3 = 1,373 yd^3 @ $10/yd^3	$ 13,730
(3)	Purchase and install automatic runoff sampler	$ 7,000
(4)	Construction of WEIR for sampler	$ 25,000
(5)	Increase warehouse by 1,000 ft^2 @ $25/ft^2	$ 25,000
		$ 387,229
	Engineering and Design	$ 38,723
	Total additional capital costs	$ 425,952

Table F. 19 (continued)

OPERATIONAL COSTS			
A. Additional Materials			
(1) Secondary System			
10,900 m = 35,763 ft @ $10.25/ft			$ 366,570
(2) System Maintenance Contingency			
5 maintenance operations @ $1.19/ft for 52,824 ft of system			$ 314,303
(3) Additional Personnel			
1-semiskilled laborer @ $15,000			$ 15,000
2-unskilled laborers @ $10,000			20,000
			$ 35,000
		Fringe:	$ 3,500
		Overhead	$ 19,250
			$ 57,750
		x 20 years	$1,155,000
C. Additional Consumables			$ 70,000
D. Additional Equipment			0
E. Additional Monitoring			
Offsite sample analysis @ average $50/sample, 50 samples/yr			$ 50,000
Total additional operational costs:			$ 1,955,873

Unit Differential Costs

$$\frac{10.38\ (425{,}952) + 1.56\ (1{,}955{,}873)}{1{,}000{,}000} = \frac{7{,}472{,}544}{1{,}000{,}000}$$

$$= \$7.47/\text{m}^3\ (\$0.21/\text{ft}^3)$$

Table F.20 Differential Costs for Weather Shielding

Assumptions:

- Tension structures employed.
- Purchase 3 tension structures having dimensions 36.6m x 190m @ $\$100/m^2$ = $695,400 apiece
- Weather shield moves during operations cost 1.5% of total capital cost and include costs for temporary help, repairs, etc.
- Costs calculated on basis of 1,000,000 m^3 of waste.

CAPITAL COSTS

3 tension structures @ $695,400 apiece	$2,086,200
Engineering and Design	208,620
	$2,294,820

OPERATIONAL COSTS

Weather shield moves	
55 moves at 1.5% of $2,294,800	$1,893,210

Unit Differential Costs:

$$\frac{10.38(2,294,820) + 1.56(1,893,210)}{1,000,000} = \frac{26,773,639}{1,000,000}$$

$$= \$26.77/m^3 = \$0.76/ft^3$$

Table F.21 Differential Costs for Stacked Waste Emplacement

Assumptions:

- Costs based upon 1,000,000 m^3 of waste disposed by stacking into reference trenches at 75% efficiency. The available disposal volume per trench is 34,460 m^3. At 75% efficiency, can dispose of 25,845 m^3 per trench. The number of disposal trenches is reduced from 58 to 39.

ADDITIONAL CAPITAL COSTS

Increase health physics/security building by 4,000 ft^2 @ $45/$ft^2$	$ 180,000
Increase garage by 1,000 ft^2@ $25/$ft^2$	$ 25,000
	$ 205,000
Engineering and Design:	20,500
	$ 225,500

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

1. Standpipes	
58 trenches @$670.50/trench	$ 38,889
39 trenches @$670.50/trench	$ 26,150
	-$ 12,739
2. French Drain	
58 trenches with 85 yd^3/trench @ $5/yd	$ 24,650
39 trenches with 85 yd^3/trench @ $5/yd	$ 16,575
	-$ 8,075
3. Seed and Mulch	
58 trenches = 87 acres @ $295/acre	$ 25,665
39 trenches = 58.5 acres @ $295/acre	$ 17,258
	-$ 8,407
4. Monuments and Markers	
58 trenches @ $122/trench	$ 7,076
39 trenches @ $122/trench	$ 4,758
	-$ 2,318
5. Surveyor	
$60/hr @ 8 hrs/trench	
58 trenches @ $480/trench	$ 27,840
39 trenches @ $480/trench	$ 18,720
	-$ 9,120

Table F.21 (continued)

B.	Additional Personnel		
	4-Radiation safety technicians @ $15,000		$ 60,000
	4-Heavy equipment operators @ $21,000		84,000
	5-Semiskilled laborers @ $15,000		75,000
	6-Unskilled laborers @ $10,000		10,000
	1-Quality assurance technician @ $14,000		14,000
			$ 293,000
		Fringe:	$ 29,300
		Overhead:	$ 161,150
			$ 483,450
		x 20 yrs	$9,669,000
C.	Consumables		$ 586,000
D.	Additional Equipment		
	4-forklifts for 240 months @ $1,000/mo		$ 960,000
	1-40 ton crane for 240 months @ 4,500/mo		$ 1,080,000
	1-onsite transport vehicle 240 months @ $2,100/mo		$ 504,000
			$ 2,544,000
E.	Additional Monitoring		0
	Total additional operational costs:		$12,758,341

Unit Differential Costs

$$\frac{10.38\ (225{,}500) + 1.56\ (12{,}758{,}341)}{1{,}000{,}000} = \frac{22{,}243{,}702}{1{,}000{,}000}$$

$$= \$22.24/m^3\ (\$0.63/ft^3)$$

Table F.22 Differential Costs for Waste Segregation

Assumptions:

- o Waste segregation requires additional labor and additional equipment
- o Costs calculated based on 1,000,000 m³ of randomly disposal waste

ADDITIONAL CAPITAL COSTS

Add atmospheric sampler @ $900		$ 900
	Engineering and Design	90
		$ 990

ADDITIONAL OPERATIONAL COSTS

A. Additional Trench Construction Materials		$ 0
B. Additional Personnel		
1-radiation safety technician @ $15,000		$ 15,000
1-semiskilled laborer @ $15,000		$ 15,000
3-unskilled laborers @ $10,000		$ 30,000
1-quality assurance technician @ $14,000		$ 14,000
		$ 74,000
	Fringe:	7,400
	Overhead:	40,700
		$ 122,100
	x 20 yrs	$ 2,442,000
C. Additional Consumables		$ 148,000
D. Additional Equipment		
1-40-ton boom crane for 240 mo. @ $4,500/mo.		$ 1,008,000
1-forklift for 240 mo. @ $1,000/mo		240,000
		$ 1,248,000
E. Additional Monitoring		
50 offsite analyses/yr @ $50/sample x20 yrs		$ 50,000
Total additional operational costs:		$ 3,888,000

Unit Differential Costs.

$$\frac{10,38(990) + 1.56(3,888,000)}{1,000,000} = \frac{6,075,556}{1,000,000} = \begin{matrix}\$6,08/m^3 \\ \$0.17/ft^3\end{matrix}$$

Table F.23 Differential Costs for Decontainerized Disposal

Assumptions:

- Costs based upon decontainerized disposal of lower activity compressible unstable waste, assumed to be about 56% of 1,000,000 m^3, or 560,000 m^3 for waste spectrum 1 (50% disposal efficiency).
- Operations require additional personnel, increased storage space, increased facility building sizes and increased airborne sampling.
- Operations require segregated waste disposal and use of weather shielding; however, costs calculated here do not include costs for segregation. (Waste segregation alternative is automatically triggered and costs included when decontainerized alternative is implemented in computer programs).

CAPITAL COSTS:

1.	Add 10 atmospheric samplers @ $900	$ 9,000
2.	Increase health physics/security building by 8,000 ft² @ $45/ft²	$ 360,000
3.	Increase garage by 1,000 ft² @ $25/ft²	$ 25,000
4.	Increase warehouse by 1,000 ft² @ $25/ft²	$ 25,000
5.	Construct additional storage area covering 6,000 ft² @ $20/ft²	$ 120,000
6.	Increase waste activities building by 6,025 ft² @ $50/ft²	$ 301,250
		$ 840,250
	Engineering and Design	$ 84,025
		$ 924,275

ADDITIONAL OPERATIONAL COSTS

A.	Additional Construction Materials	$ 0
B.	Additional Personnel	
	6-Radiation safety technicians @ $15,000	$ 90,000
	6-Heavy equipment operators @ $21,000	$ 126,000
	12-Semiskilled laborers @ $15,000	$ 180,000
	25-Unskilled laborers @ $10,000	$ 250,000
	2-Quality assurance technicians @ $14,000	$ 28,000
		$ 679,000
	Fringe:	$ 67,400
	Overhead:	$ 370,700
		$ 1,112,100
	x 20 yrs	$22,242,000

Table F.23 (continued)

C.	Additional Consumables	$ 1,348,000
D.	Additional Equipment	
	1-four wheel drive vehicle for 240 months @ $800/mo	$ 192,000
	1-pickup for 240 months @ $750/mo	180,000
	2-forklifts for 240 months @ $1,000/mo	480,000
	1-crawler tractor for 240 months @ $4,200/mo	1,008,000
	1-vibratory compactor for 240 months @ $1,950/mo	468,000
	1-farm tractor for 240 months @ $2,100/mo	504,000
	1-onsite transport vehicle 240 months @$2,100/mo	504,000
		$ 3,336,000
E.	Additional Monitoring	
	500 offsite sample analyses per year @ $50/analysis x 20 years	$ 500,000
	Total additional operational costs:	$27,426,000

Unit Differential Costs

$$\frac{10.38\ (974,275) + 1.56(27,426,000)}{560,000} = \frac{52,378,535}{560,000}$$

$$= \$\ 93.53/m^3 = \$2.65/ft^3$$

Table F-24. Differential Costs for In-Situ Dynamic Compaction of Compressible Waste

---

Assumptions:

- Costs based upon dynamic consolidation of trenches containing unstable wastes, or 1,000,000 m^3, if no waste segregation is performed.
- Dynamic consolidation costs calculated if performed by outside firm under contract.
- Compacted area = Vol/(EMP x EFF) = 312,500 m^2, where EMP = 0.5 and EFF = 6.4.
- Disposal area (347,222 m^2) requires additional clayey cover averaging 3 meters thick.

CAPITAL COSTS

Add 10 atmospheric samplers @ $900	$ 9,000
Engineering and Design:	$ 900
	$ 9,900

ADDITIONAL OPERATIONAL COSTS

A. Additional Materials

1. Additional Clay Soil
   3m x 347, 222 m^2=1,041,666 m^3 = 1,362,499 yd^3
   1,362,499 yd^3 @ $3.50/$yd^3$ — $ 4,768,747

2. Standpipes
   Repair one standpipe/trench
   58 trenches @ $223.5/trench — $ 12,963

B. Dynamic Compaction Costs

1. Dynamic consolidation @ $6.50/$m^2$
   312,500 m^2 x $6.50/$m^2$ — $ 2,031,250

2. Install new fill and compact, move, spread, and backfill earth into trenches, plus compaction of 1,362,499 yd^3 at approximately $2.00/$yd^3$ — $ 2,724,998

Table F-24 (continued)

C.	Additional Personnel		
	2-radiation safety technicians @ $15,000		$ 30,000
	1-quality assurance technician @ $14,000		14,000
			$ 44,000
		Fringe:	4,400
		Overhead:	24,200
			$ 72,600
		x 20 yrs	$ 1,452,000
D.	Additional Consumables		$ 88,000
E.	Additional Equipment		0
F.	Additional Monitoring		
	500 offsite sample analyses @ $50/analysis x 20 yrs		$ 500,000
	Total additional operational costs:		$11,577,958

Unit Differential Costs

$$\frac{10.38(9,900) + 1.56(11,577,958)}{1,000,000} = \frac{18,164,376}{1,000,000}$$

$$= \$18.16/m^3 \ (\$0.51/ft^3)$$

Cost per unit disposal area = $6.31/m²

6. REFERENCES

1. Occupational Safety and Health Administration, 29 CFR 1926.652, Construction Standards: Specific Trenching Requirements.

2. Murphy, E.S., G. M. Holter, Technology, Safety & Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570, Battelle Pacific Northwest Laboratories for NRC, June 1980.

3. McMahon, L. A., McGraw-Hill's 1980 Dodge Guide to Public Works and Heavy Construction Costs, McGraw-Hill, 1979.

4. Personal communication from Louis Reynolds, Director of Regulatory Affairs for Chem Nuclear Systems, Inc., to G. W. Roles, NRC Division of Waste Management, April 10, 1980.

5. Washington State Department of Social and Health Services Radioactive Materials License No. WN-IO-19-2, January 11, 1980.

6. Nuclear Engineering Company, Inc., The Hanford Commercial Low-Level Waste Disposal Facility, NECO 79-001, Docket No. 27-48, February 1979.

7. Personal communication from Vern Apple, Site Manager for Hanford Commercial Disposal Facility, to G. W. Roles, NRC Division of Waste Management.

8. Webster, D. A., A Review of Hydrologic and Geologic Conditions Related to the Radioactive Solid-Waste Burial Ground at Oak Ridge National Laboratory, Tennessee, U. S. Geologic Survey Open File Report 76-727, 1976.

9. U.S. Energy Research & Development Administration, Final Environmental Statement, Waste Management Operations, Hanford Reservation, Richland, Washington, ERDO-1538, December 1975.

10. Rogers, M. A., History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes, U.S. Environmental Research & Development Administration, Contract No. W-7405-Eng. 36 (LA-6848-MS, Vol. 1).

11. Chem-Nuclear Systems, Inc., Environmental Assessment for Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, January 1980.

12. Mawson, C. A., A. E. Russell, "Facilities for Waste Management at Chalk River, Canada," Proceeding from Scientific Conference on Radioactive Waste Disposal, Monaco (1959).

13. Healy, J. W., J. C. Rodgers, Limits for the Burial of the Department of Energy Transuranic Wastes, Los Alamos Scientific Laboratory, January 15, 1979.

14. O'Farrell, T. P., R. O. Gilbert, "Transport of Radioactive Materials by Jack Rabbits on the Hanford Reservation," Health Physics, Vol. 29, July 1975.

15. Cline, et al., Experimental Design for Demonstration of Bio-Barriers Placed in a Simulated Burial Trench, BNWL-2035, May 1976.

16. Webster, D. A., A Review of Hydrologic & Geologic Conditions Related to the Radioactive Solid Waste Burial Grounds at Oak Ridge National Laboratory, Tennessee, USGS Open File Report 76-727, 1976.

17. Hein, G. E., Machanlinski, Characterization of Existing Surface Conditions at Sheffield Low-Level Waste Disposal Facility, NUREG/CR-1683, August 1980.

18. Cline, J. F., Biobarriers Used in Shallow-Burial Ground Stabilization, PNL-2918, March 1979.

19. Letter from W. E. Skiens, Battelle Pacific Northwest Laboratories to G. W. Roles, NRC, Division of Waste Management, January 10, 1980.

20. Baker, R. W., H. K. Lonsdale, "Controlled Delivery on Emerging Use for Membranes," Chemtech, November 1975.

21. Burton, F. G., et al., "Fabrication and Testing of Vaginal Contraceptive Devices Designed for Release of Prespecified Dose Levels of Steroids," Contraception, Vol. 17, No. 3, March 1978.

22. Everett, G., Groundwater Monitoring, Guidelines and Methodology for Developing and Implementing a Groundwater Quality Monitoring Program, General Electric Company.

23. EPA, Procedures Manual for Groundwater Monitoring at Solid Waste Disposal Facilities, EPA/530/SW-611, U.S. Environmental Protection Agency, August 1977.

24. Dames and Moore, Developments of Monitoring Programs for ERDA Owned Radioactive Low-Level Burial Sites, U.S. Energy Research & Development Administration Contract No. E (49-1) -3759, July 1976.

25. EPA, Draft Environmental Impact Statement on the Proposed Guidelines for the Landfill Disposal of Solid Waste (40 CFR Part 241), March 1979.

26. Wallace, et al., Vegetational Cover in Monitoring and Stabilization of Shallow Land Burial Sites: Annual Report October 1976-September 1979, NUREG/CR-1358, August 1980.

27. Lutton, R. J., G. L. Regan, Selection and Design of Cover for Solid Waste, Interim Report," U.S. Army Corps of Engineers for USEPA.

28. SCS Engineers, Study of Engineering and Water Management Practices That Will Minimize the Infiltration of Precipitation into Trenches Containing Radioactive Waste, prepared by SCS for USEPA, September 17, 1977.

29. MacBeth, P., et al., Evaluation of Alternative Methods for the Disposal of Low-Level Radioactive Wastes, NUREG/CR-0680, July 1979.

30. Hawkins, R. H., J. H. Horton, "Bentonite as a Protective Cover for Buried Radioactive Waste," Health Physics, Vol. 13, 1967.

31. Personal communication from Herbert Oakley, Chem-Nuclear Systems, Inc. to G. W. Roles, NRC Division of Waste Management, April 23, 1980.

32. Kahle, R., J. Rowlands, Evaluation of Trench Subsidence and Stabilization at Sheffield Low-Level Radioactive Waste Disposal Facility, NUREG/CR-2101, Ralph Stone and Company for NRC, May 1981.

33. Dames and Moore, Remedial Program for the Low-Level Radioactive Waste Disposal Site at West Valley, New York, prepared for the New York State Energy Research and Development Authority, August 1977.

34. Chem-Nuclear Systems, Inc., Preliminary Site Stabilization and Closure Plan for the Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, May 1980.

35. Dames and Moore, Engineering Feasibility Study for Alternative Radioactive Waste Disposal Technologies in SWDA-6, prepared for Oak Ridge National Laboratory, December 1980.

36. Anderson, B. C., R. M. Schletter, A History of the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory (Draft Report), EG&G Idaho, January 1980.

37. Menard, Inc., Foundation Improvement by Dynamic Consolidation, undated.

38. Menard, Dynamic Consolidation, undated.

39. Wild, R., et al., Data Base for Radioactive Waste Management, Vol. 2, Waste Source Options, NUREG/CR-1759, Dames and Moore for U.S. NRC, to be published.

40. Kniazewycz, B. G., G. Trigilio, Volume Reduction Techniques in Low-Level Radioactive Waste Management, Teknekron, Inc. for U.S. NRC, to be published.

41. ERDA, Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, Energy Research and Development Administration, May 1976.

42. Pereira, P. E. (ed.), McGraw-Hill's 1980 Dodge Manual for Building Construction Pricing and Scheduling, Annual Edition No. 15, McGraw-Hill, 1979.

43. Pereira, P. E. (ed.), McGraw-Hill's Dodge Construction Systems Costs McGraw-Hill, 1979.

*U.S. GOVERNMENT PRINTING OFFICE: 1981-0-341-742/1310

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG-0782, Vol. 3

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Draft Environmental Impact Statement on 10 CFR Part 61: "Licensing Requirements for Land Disposal of Radioactive Waste", Appendices A-F

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
NRC Staff

5. DATE REPORT COMPLETED
MONTH Sept. | YEAR 1981

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, DC 20555

DATE REPORT ISSUED
MONTH Sept. | YEAR 1981

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Same as 9.

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.

13. TYPE OF REPORT
Draft Environmental Impact Statement

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)

The four volume draft environmental impact statement (DEIS) is prepared to guide and support publication of a proposed new regulation, 10 CFR Part 61, for the land disposal of low-level radioactive waste. The analysis in the DEIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design of disposal facilities, the method of operation of the facilities, institutional controls, financial assurances, and administrative and procedural requirements. From the analysis, four main performance objectives are established in the proposed regulation relating to (1) minimizing long-term social commitment and costs, (2) minimizing long-term environmental releases, (3) minimizing long-term impacts to humans potentially inadvertently intruding into disposed waste, and (4) assuring short-term operational safety. Based upon the analysis and overall performance objectives, a number of technical, financial, procedural, and administrative requirements are also developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
groundwater migration
inadvertent intrusion
10 CFR Part 61
waste form
financial assurances
institutional controls
radioactive waste
disposal technologies
cost-benefit analysis

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

21. NO. OF PAGES
350

20. SECURITY CLASS (This page)
Unclassified

22 PRICE
$

Newman

NUREG-0782
Vol. 4

Draft Environmental Impact Statement

on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices G-Q

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street., N.W.
   Washington, DC 20555

2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, transactions, and codes and standards. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

NUREG-0782
Vol. 4

Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste"

Appendices G-Q

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

September 1981

VOLUME IV

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Page

Appendix Q Calculation of Preoperational, Operational, Closure and Institutional Control Costs

List of Tables

List of Tables (Continued)

List of Tables (Continued)

List of Figures

Appendix G

IMPACT ANALYSIS METHOLOLOGY

This appendix presents the methodologies utilized to calculate potential impacts resulting from the management of low-level radioactive waste (LLW). The appendix is summarized from information contained in Reference 1. The appendix considers three phases of waste management that may result in various types of impacts: (1) processing of the waste at the generation source or at a centralized location prior to disposal, (2) transportation of the waste from the generation source to a disposal facility, and (3) disposal of the waste.

The methodologies considered in this appendix include calculational procedures to determine:

- the occupational exposures and the exposure of the members of the public (individuals and population) resulting from the disposal of LLW;
- the occupational and the population exposures resulting from processing of the waste by either the waste generators or by operators of a centralized regional processing facility (assumed to be located nearby the disposal facility site);
- the occupational and the population exposures resulting from transporting the waste from the waste generators to the disposal facility site;
- the costs and the energy use associated with processing, transportation, and disposal of LLW; and
- the land area committed to disposal of LLW.

Thus, the calculational methodologies are used to determine five basic "impact measures" for consideration in the EIS--i.e., dose to members of the public, occupational exposures, costs, energy use, and land use.

These methodologies may be applied to a number of alternatives for waste form and packaging, facility design and operation, and institutional controls to determine performance objectives and technical requirements for acceptable disposal of the wastes and to determine the environmental impacts of the selected alternatives.

Section 1 provides an overview of the purpose and application of the impact analysis methodologies, presents a background rationale for the fundamental assumptions utilized in the development of the methodology, and presents the approaches adopted to define the interfaces of the three waste management phases.

Section 2 discusses the pathways involved in the calculation of exposures to members of the public. It includes a discussion of the basic rationale and background of the pathway analysis methodology, presents and analyzes the generic pathways considered in this report, and develops the equations applied in subsequent sections.

Sections 3, 4, and 5 address the three phases associated with the management and disposal of LLW, and discuss the disposal impact measures, transportation impact measures, and waste processing impact measures, respectively. Additional backup data and discussion regarding the pathway analyses may be found in Reference 1.

1. INTRODUCTION

The primary purpose of the impact analysis methodology is to provide a tool to enable determination of specific values of parameters that can be controlled and/or specified through technological or administrative action so as to assure the long-term and short-term protection of the human environment.

The secondary purpose of the impact analysis methodology is to enable calculation of the selected impact measures associated with a given disposal facility design containing several waste streams each having different characteristics.

1.1 General Approach

The most important rationale governing the selection of the methodologies and the calculational procedures used in this appendix is the generic nature of the analysis. The methodologies are focused toward helping to establish generic criteria for LLW management and disposal rather than calculating impacts at a particular disposal facility.

This is especially significant in view of the level of information available for a generic analysis as opposed to the level of data which will be available for a specific disposal facility site. Increased complexity and sophistication of a calculational procedure cannot compensate for a lack of data. Moreover, increased complexity and sophistication cannot compensate for the fact that all calculational procedures are based on an idealized picture of the system; this is an integral aspect of all predictive tools which are an essential part of many decisionmaking processes. Therefore, the sophistication and level of complexity of the calculational procedures should be consistent with the level of data that can be inferred and/or generalized for a generic system.

There are many possible methods or combination of methods which may be used to calculate the potential impacts of LLW disposal; these range from very simple to very complex techniques (Refs. 1-6). Complex calculations may be called for when analyzing a specific site where a significant quantity of site-specific information is available and where specific facility designs for waste disposal may be considered. However, for generic types of analyses to support an environmental impact statement and a rulemaking effort, where one is interested in the relative costs and impacts of alternative actions, simpler calculational schemes appear to be more appropriate. This concept of increasing the complexity of calculational schemes with the increasing amount and specificity of the available data is consistent with the concept of tiering as set out by regulations promulgated by the Council on Environmental Quality (CEQ) (Ref. 7).

A second governing rationale for the selection of the methodologies and the calculational procedures in this appendix is the necessity to consider viable alternatives during three different waste management phases (waste processing, transportation, disposal) and the requirement that the interfaces of these three phases be properly coordinated. For example, waste processing techniques which reduce waste volumes would also likely result in an overall increase in the radioactive contents of the waste packages. This may result in additional transportation and disposal requirements that should be represented. Another example factor complicating an accurate definition of the interfaces is the possibility that the waste processing may occur at the waste generator's site or at a centralized regional location. This aspect has to be included in the calculation of the impact measures.

A third rationale for the selection of the methodologies is the need to have a flexible tool that can be updated as additional information is obtained. Any methodology that cannot accommodate timely changes is bound to become obsolete in a short time. The methodologies selected provide for continuous updating of the calculational techniques and the data base used for the analyses.

To develop the calculational procedures, a reference near-surface disposal facility design is assumed and a description of this disposal facility design is provided in Appendix E. In addition, the continental United States is assumed to be divided into four regions corresponding to the five NRC regions (see Figure D.1 of Appendix D). The four regions considered include the northeast (NRC Region I), the southeast (NRC Region II), the midwest (NRC Region III), and the west (NRC Regions IV and V). In each region, a hypothetical regional disposal facility site is characterized (see Appendices E and J). These sites, while not representing any particular location within a region, reflect typical environmental conditions within the regions. This allows consideration in the calculational methodology of a range of environmental conditions such as the amount of rainfall or the average distance from the waste generator to the disposal facility. (One of these sites, the southeast site, is frequently referred to in this appendix as the reference disposal facility site.)

The calculational methodology also allows consideration of a wide range in waste forms and processing options. In many previous studies on LLW disposal, the disposed waste was usually assumed to be a mostly uncharacterized mass with little attempt to distinguish in a quantitative manner the different waste forms. In this EIS, however, LLW has been separated into 36 waste streams, including nuclear fuel cycle wastes such as filter cartridges and ion exchange resins, as well as nonnuclear fuel cycle streams such as sealed sources and biological wastes. As described in Appendix D, each waste stream is characterized in terms of its radionuclide concentration (up to 23 different radionuclides are considered), its relative ability to burn, its stability over the long term, and other properties. The volumes of each waste stream are considered on a regional basis. That is, the volume of each waste stream is projected for each of the four regions over the next 20 years, which again allows consideration of the regional impacts of management and disposal of LLW.

In this EIS, four generic alternative waste form and processing options are considered. These generic processing options, called "waste spectra," represent four relative levels of waste processing activities applied to the 36 characterized waste streams. The spectra were developed to limit the number of waste form and packaging alternatives that would have to be analyzed, since an indefinitely large number of possible combinations of various waste streams and processing options are available. The four spectra, which are described in detail in Appendix D, are as follows. Waste spectrum 1 characterizes existing and, in some cases, past waste management practices. Waste spectrum 2 characterizes improvements in the form of the waste through processing and reduction in waste volume with relatively modest expenditures of time and money. These two spectra bound existing waste management practices, which are currently in a marked state of change due to state initiatives, a lack of disposal capacity, and economic considerations. Waste spectrum 3 characterizes further waste form improvements and volume reduction at further increased costs, while waste spectrum 4 characterizes the maximum volume reduction and improved waste forms that can currently be practically achieved. The 36 waste streams corresponding to a given waste spectrum may be transported to and disposed into disposal facilities located at the regional sites and the resulting potential impacts calculated. A number of alternative disposal facility design and operation alternatives (e.g., thicker disposal cell covers, use of cement grout) may be then considered to estimate the effect of these alternatives upon the impact measures.

From the above, it can be seen that when considering the effect of alternative regional, waste form, and facility design characteristics on the magnitude of the impact measures calculated, an extremely large number (thousands) of possible permutations can be considered. To enable development of performance objectives and technical requirements for LLW disposal, the number of these permutations should be controlled and analyzed on a systematic basis. To do this, two features have been adopted: (1) use of a reference disposal facility and a reference waste volume distribution and (2) extensive use of computer technology, including use of waste form and disposal technology indices.

For the first feature, a reference disposal facility is described in Appendix E, which is assumed to be located in the humid eastern United States. For this EIS, the reference disposal facility is assumed to have environmental characteristics corresponding to the southeast regional site, although either the northeast regional site or the midwest regional site could have been used for this purpose. As discussed in Appendix D, this reference waste volume distribution is generated through averaging of all the waste volumes assumed to be generated in each of the 36 streams for each of the four regions, and normalizing these volumes to one million m^3 of waste for waste spectrum one. This allows the effects of alternative waste spectra and alternative disposal facility design and operational options to be compared on a common basis.

For the second feature, five computer codes have been written to manipulate the alternatives and to determine impact measures. These include the codes INTRUDE, GRWATER, OPTIONS, INVERSI and INVERSW, and a description of each of these codes is provided in Appendix H. In these codes, extensive use of integer "indices" have been used to characterize waste stream properties or disposal facility environment and design options. For example, a specific index (the "leachability index," I6) in the codes represents the relative degree that a particular waste stream resists leaching by water percolating through a disposal trench cover. The integer value given to this index for a particular waste stream can change from one spectra to the next. Depending upon the index value, the leaching fraction assumed for the waste stream is altered in the calculations. As another example, the index IC (the "cover index") represents alternative disposal cell cover designs. Setting the index to a specific integer value results in the codes in a variation in the calculated impact measures which would be influenced by the cover thickness (e.g., groundwater impacts, costs).

Use of the integer indices enables rapid and convenient consideration of alternatives for rulemaking. In addition, use of the indices enables any updates of the data base and calculational procedures to be readily accomplished without changing the value of the indices or the structure of the calculational methodology. In the remainder of this appendix, and in particular, Sections G.3-G.5, the calculational procedures are developed and discussed in the context of these indices.

1.2 Impact Measures

The impact measures quantitied in this EIS to determine a preferred alternative or option associated with the management and disposal of LLW are summarized in Table G.1. These impact measures can be summarized into five groups: dose to members of the public, occupational exposures, costs, energy use, and land use. Two of these measures--individual and population exposures associated with the handling and disposal of the waste--are representative of the level of short- and long-term protection of the human environment from radiological impacts.

The other measures--e.g., costs, energy use, and committed land area associated with the disposal of waste--are representative of the level of long-term protection of the human environment from socioeconomic impacts. Other potential impact measures, such as man-hours and material requirements (e.g., clay, gravel, concrete), are implicitly included in the above five impact measures. In view of past disposal history and practices, impact measures related to long-term protection of the human environment are stressed.

The methodologies selected for determination of individual and population exposures resulting from the disposal of waste, which are discussed in Section 3, are primarily geared towards the generic nature of the analysis. Accordingly, determination of the relative effects of various barriers between the waste and the human environment--waste form and packaging, site selection, site design and operation, and institutional controls--occupy a prominent place in the formulation of the calculational procedure for the disposal

Table G.1 Quantifiable Impact Measures Considered in the EIS

Waste Management Phase	Impact Measure
Waste Processing	Costs Energy Use Occupational exposures due to waste processing Population exposures due to waste incineration
Waste transportation	Costs Energy use Occupational exposures Population exposures
Waste disposal	Costs Energy use Land use Occupational exposures Exposures to individuals and populations due to: o operational accidents o ground-water migration o inadvertent human intrusion

impacts. Potential occupational exposures from waste disposal are calculated based upon assumptions regarding the interface between waste transportation and waste disposal. In comparison, calculation of other impact measures--cost, energy use, and land use--is relatively straightforward based on the information and assumptions presented in the other appendices of this environmental impact statement and other references (Refs. 1-6).

The impact measures associated with waste processing and transportation--i.e., occupational and population exposures, costs, and energy use--are all representative of the level of short-term protection of the human environment afforded by the alternatives considered; it is assumed that no land is permanently committed during waste processing and transportation activities. Again, impact measures other than these four are implicitly included in the selected set of measures.

The transportation impact measures are straightforward functions of the packaging and shipping mode assumptions detailed in Section 4, and the population exposure calculational procedures given in documents such as References 8 and 9. Impact measures associated with waste processing, presented in Section 5, are calculated based on the assumptions presented in Reference 6 and the transfer factors developed in Reference 1.

2. PATHWAY ANALYSES

After the waste has been disposed of through an acceptable method, control mechanisms such as waste form (processing), site selection, site design and operation, site closure, and institutional controls begin to function. It is these control mechanisms that constitute "barriers" which confine and control to acceptable levels the interaction of the waste with the environment. This section discusses the mechanisms through which the waste may interact with the environment after disposal, and provides an overview of the interaction mechanisms in terms of applicable control mechanisms and the characteristics of the disposal system. The characteristics of the disposal system include those associated with waste form and packaging (see Appendix D), facility design and operation (see Appendices E and F), and administrative requirements.

2.1 Introduction

There are many diverse mechanisms through which radionuclides contained in LLW may be potentially released (i.e., mobilized from the waste and become accessible to a transport agent such as wind or water), transported through the environment (i.e., moved from one location to another through the atmosphere or soil by a transport agent), and thereby become accessible to humans through various pathways. Human access to the radioactivity may result either through direct human contact with contaminated material (e.g., inhalation of air, ingestion of water, or direct exposure to radiation) or indirectly through contaminated biota (through a multitude of pathways involving vegetation and animals) which have come into contact with contaminated material.

Each of these radionuclide release/transport/pathway combinations (scenarios) represents a complex series of interactions which are affected by a wide range of parameters such as waste properties, disposal site properties, and operational procedures. These diverse release/transport/pathway scenarios should be unified so as to achieve a simple, accurate, and readily usable methodology for pathway analysis. The development of the methodology employed in this EIS for pathway analysis is based on the following procedure:

- Define and analyze the potential release/transport/pathway scenarios that may lead to radiation exposures to either individuals or populations, and select the significant scenarios for future analysis.

- Simplify the structure of the selected release/transport/pathway scenarios by separating the radiation release and transport mechanisms from the pathway mechanism. In other words, separate the calculational procedures used to model release of radionuclides and movement through the environment from those calculational procedures used to model the resulting dose to humans.

- Determine applicable radionuclide-specific dose conversion factors for various human organs for human exposure to contaminated material for all release/transport/pathway scenarios. The dose conversion factors, henceforth called the pathway dose conversion factors (PDCFs) to distinguish them from the conventional use of the term "dose conversion factor," are determined for an entire pathway to permit rapid determination of dose equivalent rates to human organs.

- Model the radioactivity release and transport mechanisms between the disposed wastes and the locations where the radionuclides may be contacted by humans (the "biota access locations"). Then, identify the control mechanisms and barriers that may be technologically or administratively implemented that affect these release and transport mechanisms.

- Utilizing the information presented in Appendices D, E, and F, determine the various options available for these control mechanisms in terms of waste form, site selection, site design, site operation, and institutional requirements.

- Finally, determine the potential radiological impacts from the disposed LLW for various alternative options.

The methodology considers only one radionuclide at a time. Total impacts resulting from the movement of radionuclides from the waste and through the environment are obtained by summing over all of the radionuclides assumed to be present in the LLW. Several radionuclides considered, however, result in decay chains (Ref. 6). These decay chains are implicitly included by incorporating the effects of the daughters through the dose conversion factors for the parent radionuclide or by decaying the appropriate fraction of the parent radionuclide and adding it to the daughter radionuclide inventory (as in the example case of the decay of Pu-241 to Am-241).

2.2 Release/Transport/Pathway Scenarios

In accordance with the first two steps outlined above, the definition and simplification of the potential release/transport/pathway scenarios that are quantifiable and can lead to significant radiation exposures to humans are discussed in this section.

2.2.1 Approach

The conventional approach to quantifying the routes and pathways between radioactive materials and humans, and thereby determining the resulting radiological impacts, is widely known and can be found in the literature (Refs. 10, 11). A representative diagram is given in simplified form in Figure G.1.

As shown in this figure and beginning with the disposed waste, the transfer of radionuclides (and/or direct gamma radiation) is traced along numerous transport paths as the contamination is transferred between adjoining compartments and is eventually taken up by humans. The boxes represent the contaminated media and the arrows indicate that containment transfer can occur between adjacent compartments via the stated radionuclide-mobilizing mechanism.

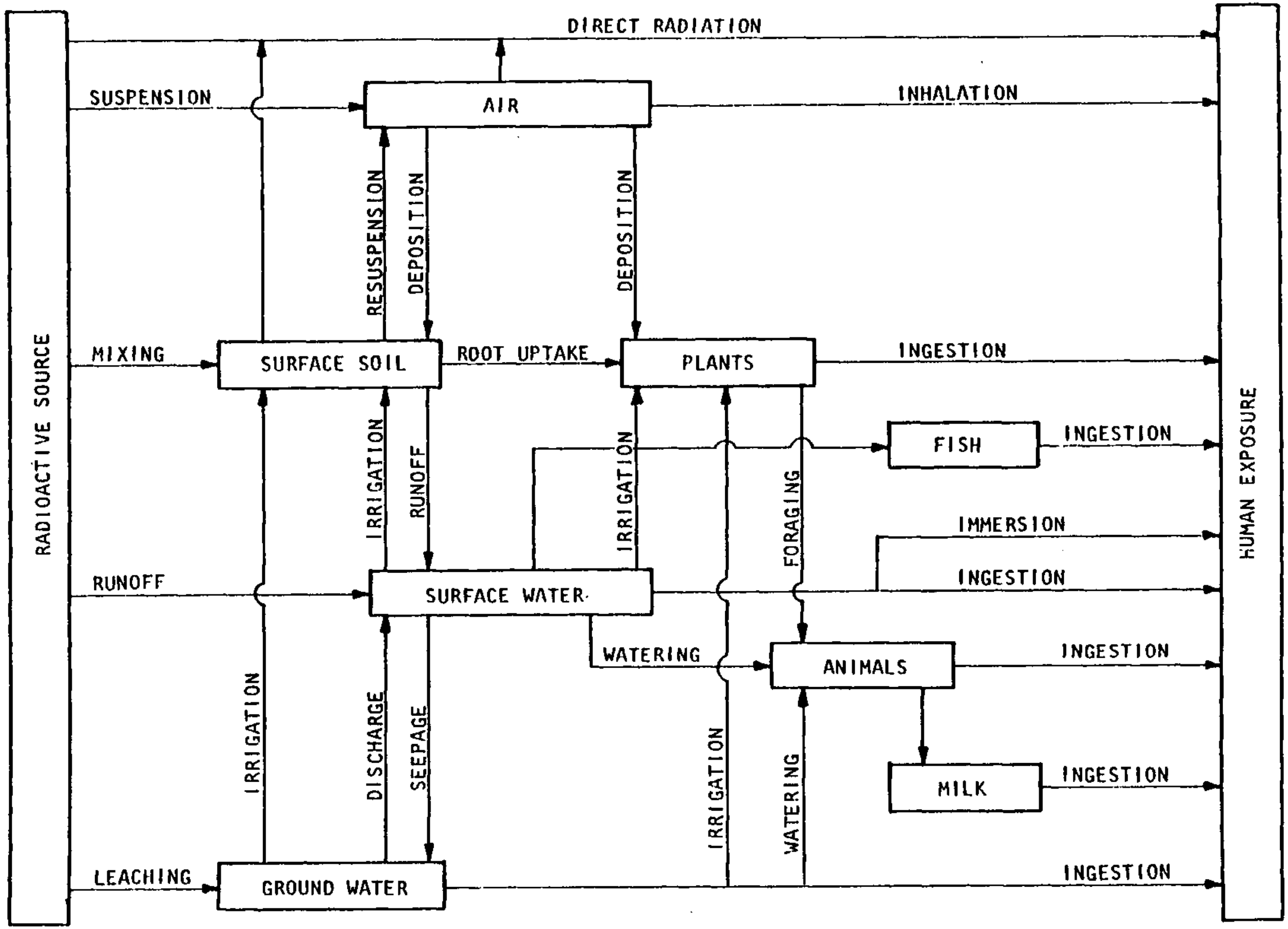


Figure G.1 Example Classical Pathway Diagram

This classical pathway methodology is very useful in determining specific impacts associated with a particular disposal facility, but is unfortunately a bit awkward for use in determining generic regulatory requirements. This results from the fact that most of the arrows between the boxes represent environmental parameters that are site-specific. Moreover, the diagram does not permit rapid identification and analysis of alternative control mechanisms, which may be used to reduce or eliminate the potential radiological impacts.

To aid in analyzing alternative overall performance objectives and technical criteria, a more practical calculational procedure is needed which separates those parameters that can be controlled (through technological and/or administrative requirements) with a high degree of confidence from those that cannot be controlled with the same degree of confidence. For example, waste form and packaging are parameters that may be potentially controlled with a higher degree of confidence than such parameters as the irrigation rate of crops, which must be assumed to be uncontrollable. A pathway diagram that has been rearranged in order to satisfy these conditions is presented in Figure G.2.

As can be seen in this figure, most of the site-secific pathway compartments and parameters have been separated from the rest of the diagram at the biota access locations. Most of the parameters which can be controlled (which are the solid waste/soil mixture box and the connections of this box with the other biota access locations) have been separated from the rest of the diagram. The significance of this separation is that performance objectives, technical requirements, and administrative regulations which would be formulated to reduce the radiological impact of LLW disposal would be aimed at the controllable parameters.

After contamination reaches a biota access location, it becomes available for immediate or eventual uptake by humans. Comparatively little control (mostly through site selection) can be implemented over the segments of the pathways beyond these biota access locations (e.g., selection of a desert location may minimize ingestion pathways). Because of this comparative lack of control, movement of radionuclides through the pathways beyond the biota access locations and resulting human exposures may be expressed through radionuclide specific pathway dose conversion factors (PDCFs) that are independent of the original means of contamination. Based on an appropriate reference concentration at the biota access location (e.g., 1 curie/m^3 of contaminated media), the dose to humans may be calculated for each pathway from the biota access location to the point of eventual human exposure. In other words, once the radionuclide concentrations at the biota access locations are known, potential human exposures may be determined by multiplying the actual access location concentration C_a (in units of Ci/m^3) by the PDCF (in units of millirem per Ci/m^3):

$$H = PDCF \times C_a \qquad \text{(G-1)}$$

where H is the human dose in millirem (see Section 2.4). As an example of the development and use of a particular PDCF, consider the impacts that could result to a human from the presence of a concentration of radioactivity in offsite air. Potential exposures could result from the following uptake pathways:

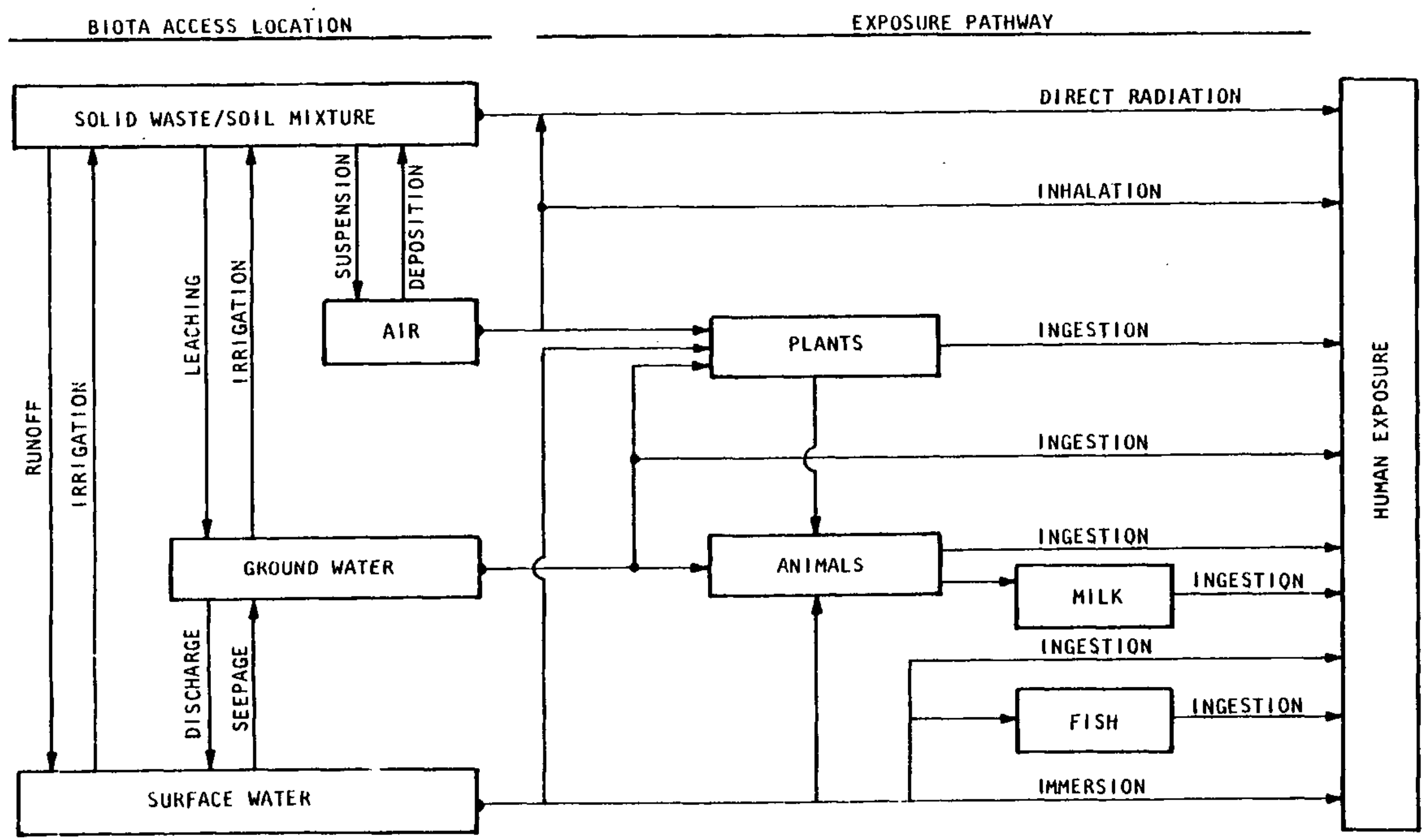


Figure G.2 Modified Pathway Diagram Illustrating Biota Access Locations

- o Inhalation of the contaminated air;
- o Direct gamma exposure from standing in the contaminated air;
- o Consumption of leafy vegetables dusted with radionuclides settled out of the air;
- o Direct gamma exposure from contaminated dust deposited on the ground;
- o Inhalation of contaminated dust which has been resuspended from the ground surface;
- o Consumption of vegetables containing radionuclides transferred into the plant through root pathways; and
- o Consumption of food containing radionuclides transferred to the food through various pathways such as plant-animal-meat or plant-animal-milk.

At a specific site, the dose resulting from these uptake pathways would be determined through the use of (1) transfer factors such as the air-to-leaf and soil-to-air transfer factors and (2) fundamental dose conversion factors (DCF) such as the inhalation DCF (50-year committed dose per pCi inhaled) and ingestion DCF (50-year committed dose per pCi ingested).

The transfer factors and the actual potential impacts would be specific to particular environmental conditions (e.g., humidity, types of food grown, etc.) and specific human actions at the location where the airborne contamination occurred. However, for generic analyses, reasonable yet conservative assumptions may be made regarding such environmental characteristics and human actions. Based upon these assumptions, the potential individual organ dose that could occur as a result of each uptake pathway can be calculated. The doses from each uptake pathway may be then summed to form, for each individual organ, a single pathway dose conversion factor that represents the total potential dose received from all uptake pathways. The end result is the ability to quickly determine on a generic basis (e.g., by consulting a table and multiplying), the total potential organ doses received by a human from any concentration of radionuclides in air.

This approach introduces a conservatism in the calculation of doses since not all of the uptake pathways may be applicable for every release pathway and environmental setting. The generic nature of the analysis, however, precludes a detailed consideration of site-specific pathway factors.

2.2.2 Release/Transport Mechanisms

This section discusses in more detail the release/transport mechanisms considered in this appendix. It is broken up into three subsections. In the first subsection, the release scenarios are discussed in relation to the transport agents potentially mobilizing the radioactivity in addition to the time periods during which the radioactivity may be mobilized and/or reach a biota access location. The second subsection (Section 2.2.2.2) describes the separation of the calculational methodology into control mechanisms. The specific release/transport scenarios considered in this section are then described against the background of the first two subsections. These scenarios are separated into those which are principally a function of the radionuclide concentrations in the waste (the "concentration scenarios," Section 2.2.2.3), those which are principally a function of the total inventory of radionuclides in the waste (the "total activity scenarios," Section 2.2.2.4), and other short-term scenarios associated with processing, handling, and transporting the waste (Section 2.2.2.5).

2.2.2.1 Timing of Release/Transport/Pathway Scenario

There are three fundamental transport agents which can mobilize radioactivity from disposed waste:

- Direct Contact--The waste may be directly accessed by humans through gama-ray exposure or through human activities which contact the waste/soil mixture.
- Air--Air can mobilize radioactivity from the waste when the waste is directly exposed to or released into the atmosphere.
- Water--Ground water and surface water can act as transport agents to mobilize radioactivity from the waste.

Moreover, there are two comparatively distinct time periods of the site lifespan during which releases from LLW can reach a biota access location: the operational period and the postoperational period. The postoperational period may be further divided into the closure and observation period, the active institutional control period, and the passive institutional control period.

Operational Period--The operational period includes the time during which waste disposal operations take place. During this period, the principal mechanism at a disposal facility that can result in significant transport of radioactivity to a biota access location is an operational accident. In this case, wind is the primary transport agent, the biota access location becomes offsite air, and the exposure period is acute--i.e., a discrete event occurring over a short time span.

During this period, the site operator is responsible for the control and maintenance of the site. Potential impacts from operational accidents are important but not directly related to the long-term performance of a near-surface disposal facility. Operational accidents are important insofar as potential operational releases may be precluded or minimized by improvements in waste form and packaging or site operational procedures. Potential offsite exposures due to surface run-off from contaminated onsite soil may occur; however, they are not quantitatively analyzed in the EIS. Such potential short-term exposure would be addressed as part of licensing specific disposal facilities. Routine occupational exposures during the operational period are considered in Section G.3. Ground-water migration is not calculated during this period for calculational convenience, and because of the short time span and operational measures that would be taken to minimize the potential for migration.

During the operational period, other short-term exposures would also result at locations other than the disposal facility site. Exposures to populations could result from airborne releases of radioactivity during waste processing activities--especially if such processing activities involve incineration of combustible waste streams. Such processing activities would be performed by the waste generator or at centralized processing centers. Population exposures would also occur during waste transportation to the disposal facility. Occupational exposures would result to waste handlers while generating and processing waste streams, as well as to personnel transporting the waste to the disposal facility.

Closure and Observation Period--This period lasts from the end of disposal operations at the facility to the time that the title for the facility is transferred to the site owner. The period begins during the time that the disposal facility is closed and lasts through any period of observation carried out by the site operator to assure that the disposal facility is in a stable condition prior to transfer to the site owner. During this period, the facility operator is responsible for the control and maintenance of the site. The ground-water scenario is initiated during this period.

Active Institutional Control Period--The active institutional control period lasts from the transfer of the title of the site by the site operator to the site owner until a point in time at which a breakdown in institutional controls is assumed to occur. During this period, the waste is not exposed to the atmosphere. The waste may, however, interact with humans through direct radiation attenuated through the disposal cell cover. Thus, the waste itself is an access location. The other principal agent that can transport radioactivity from the waste during this period is ground water, which may transport the radioactivity to locations where the radioactivity may be accessed by humans. Possible access locations could include either a well drilled into the contaminated aquifer or open water (e.g., a stream) into which the contaminated aquifer has discharged. For both of these cases the exposure periods are chronic (i.e., continuous events).

Prior to the transfer of the title to the site owner, the site will be closed by the site operator. A desirable goal during the closure activities is that the site will have been stabilized so that there is essentially no need for active ongoing maintenance by the site owner. During the active institutional control period, the site owner is responsible for the care, surveillance, and maintenance of the site. Access to the site is restricted (e.g., fenced) and/or controlled by means of some manner of licensed surface use. The direct radiation exposure scenario, in comparison with other scenarios, is likely not to be significant since the radiation must pass through the intact trench cover. However, the ground-water scenario is assumed to continue during this period.

Passive Institutional Control Period--During the passive institutional control period (after active institutional controls are assumed to have ceased), the waste may be exposed to the atmosphere through erosion or human activities. During this period, the waste/soil mixture may be potentially directly accessed by humans. For example, a house could be inadvertently constructed on the waste disposal facility and, after the house is constructed, a person or small group of persons could live in the house and possibly consume garden vegetables grown in the soil/waste mixture. In addition, wind and water may act as transport agents that may lead to dispersion of radionuclides and offsite contamination. The ground-water scenario continues during the passive institutional control period.

During the active institutional control period, it may be assumed that active controls exercised by the site owner on the closed disposal site will gradually lessen. The period of time between the site inspection and routine monitoring of the site will lengthen.

Eventually, a passive institutional control period may be assumed during which the control of the site is principally expressed through site ownership and control of land use. During this period, there may be occasions in which inappropriate use of the facility by humans occurs. As extreme examples of inappropriate use, a house may be constructed on the disposal facility and persons may live in the house. It is likely, however, that the passive institutional controls would preclude continuation of inappropriate site use for long time periods.

2.2.2.2 Control Mechanisms

The release and transport of radioactivity from the disposed of LLW are significantly affected by the properties and characteristics of the waste form and packaging, site design and location, disposal practices, etc. Most, if not all, of these items are controllable to some degree. Specific controls of these items can be made mandatory through administrative regulation; hence, these may be termed regulatable items or control mechanisms.

In order to permit the specification of controls and the quantitative assessment of their effects, these control mechanisms should be identified unambiguously. To accomplish this, each release/transport mechanism may be broken down into its component parts.

For example, consider the action of rainwater on a near-surface disposal facility. Rainwater (the initial form of the transport agent) may seep down into the waste, contact and leach radioactivity from the waste (thereby becoming leachate), become contaminated and continue seeping downward. The contaminated water may then move through the transport medium to a well or to a river (biota access location) where it is withdrawn for use in human consumption, crop irrigation, animal watering, etc. The following barriers and control mechanisms can be identified:

- Rainwater infiltration into the waste cell can be reduced by a low-permeability clay cover over a waste disposal trench. This barrier can be controlled through site design and stabilization operations during site closure.

- Water that does enter the trench can be partially inhibited from picking up contamination from the waste by either assuring that the waste container does not permit contact between the waste and water (this may be accomplished through the use of a high integrity container) or by permitting only the disposal of waste that releases radioactivity very slowly upon contact with water. This barrier can be controlled through waste form and packaging.

- Release of contaminated water from the trench may then be reduced by another low-permeability clay layer at the bottom of the trench. However, this barrier may be undesirable and should be utilized with caution. Accumulation of leachate could occur which could fill up the trench and eventually possibly lead to overflow of the trench. This barrier can be controlled through site design.

- After the water enters the transfer medium (i.e., the soil), natural geologic barriers can impede and/or reduce the magnitude of the radionuclide transfer. These barriers can be controlled through site selection and include adsorbtion onto soil particles as the water moves through an underlying strata, dispersion of the radionuclides migration, and radioactive decay during travel through the geologic medium.

- Once the transport agent reaches the biota access location, another mechanism that would reduce the magnitude of the contaminant concentration is dilution with uncontaminated water at the discharge location. For example, the flow rate of a river or the pumping rate of a well affects the degree of dilution achieved. This barrier can also be potentially controlled through site selection.

- Finally, the point in time at which the ground-water scenario is initiated depends on waste form and packaging, site operational procedures, and administrative requirements. For example, the waste may be packaged in a high integrity container. This results in a time-delay factor, due to radioactive decay, that can reduce the magnitude of the source term significantly.

The barrier concepts that have been discussed above can be generalized and applied quantitatively to each release/transport scenario. This may be accomplished by using an <u>interaction factor</u> (denoted by the symbol I) that relates the radionuclide concentration in the biota access location to the radionuclide concentration in the waste:

$$C_a = I \times C_w \qquad \text{(G-2)}$$

where (C_a) and (C_w) are the concentrations of the radionuclide of concern, in units of (Ci/m^3), at the biota access location and in the waste, respectively. The interaction factor (I) can further be compartmentalized in terms of the barriers discussed above:

$$I = f_o \times f_d \times f_w \times f_s \qquad \text{(G-3)}$$

where

f_o = <u>time-delay barrier factor</u>. This factor accounts for all the control mechanisms that increase the time period between termination of waste disposal at the site and the initiation of contact between the transport agent and the waste.

f_d = site design barrier factor. This factor includes the effects of any engineered barriers designed into the waste disposal facility, plus any site operational practices that may reduce transport.

f_w = waste form and package barrier factor. This factor accounts for the physical and chemical characteristics of the waste at the time of the initiation of the release/transport scenario that may inhibit contaminant transfer to the transport agent.

f_s = site selection barrier factor. This factor includes the effects of the natural site environment that contribute to reducing the containment concentrations at the biota access location.

These four factors may be used to represent the control mechanisms. These four factors are not the barrier criteria themselves, but may be used to help determine the barrier criteria. Regulation through these factors may be accomplished by either specifying the value required for a given barrier factor, or by defining the characteristics of the barrier needed to achieve the desired effect.

For the remainder of this appendix, the release and transport of radionuclide from waste at a disposal facility is described in terms of these four barrier factors.

2.2.2.3 Concentration Scenarios

Three scenarios whose impacts are a function of the concentrations of radionuclides in the waste streams are considered in this section. The first scenario considered concerns accidents that may happen during the operational period of the disposal facility lifespan, and which may result in offsite atmospheric transport of radionuclides. The other two scenarios are concerned with exposures to a potential inadvertent intruder. An intruder may unintentionally come across a closed waste disposal site due to a temporary breakdown in institutional controls, and subsequently modify it for a specific purpose such as housing construction or agriculture. As a result, short- and long-term radiation exposures to the individual can ensue.

Two of the concentration scenarios (accident and inadvertent intruder-construction) are acute exposure events. Thus, the release and subsequent exposure occurs for a limited period of time (less than a year). The other scenario (inadvertent intruder-agriculture) is assumed to be chronic, since it is possible (but very unlikely) that the intruder would live for several years at the site before it is discovered that there is a hazard.

Few individuals are expected to be involved in the concentration scenarios, and they may also be distinguished from the total activity scenarios by the dose limitation criteria which may be applied. Different limits on allowable human doses may be used, depending upon whether a few individuals or populations are exposed. The equation generally applicable to the concentration scenarios is:

$$C_a = I \times C_w \qquad \text{(G-2)}$$

where (C_a) denotes the radionuclide concentration at the biota access location and (C_w) denotes the radionuclide concentration of the waste, both in units of (Ci/m^3), and (I) is the dimensionless interaction factor, which depends on the specific scenario considered.

For these scenarios, the undecayed radioactive concentrations are utilized which neglect any decay during the operating life of the site (Ref. 1, 6). This is a conservative assumption for the construction and agriculture scenarios since the inadvertent intruder may initiate the scenario at a location containing waste from the first year of facility operation.

The interaction factor (I) can generally be expressed through the following equation:

$$I = f_o \times f_d \times f_w \times f_s \qquad \text{(G-3)}$$

where all the parameters are dimensionless, and where

f_o = time-delay factor;
f_d = site design and operation factor;
f_w = waste form and package factor; and
f_s = site selection factor.

The time-delay factor (f_o) is expressed as a radionuclide decay factor and incorporates the effects of the closure period and the active institutional control period. The activities are decayed to the time that the specific scenario is initiated. This factor is a property of the scenario and the disposal technology being considered. For the accident scenario, no credit for radioactive decay can be assumed and (f_o) will be taken to equal one. However, for the construction and agriculture scenarios, it is given by the formula:

$$f_o = \exp[-\lambda T] \qquad \text{(G-4)}$$

where λ is the radionuclide decay constant in units of 1/year, and T is the period of time between the cessation of disposal operations and the end of the active institutional control period.

The site design and operation factor (f_d) expresses the waste fraction that is available to the transfer agent. It usually depends on the efficiency of the disposal design. Furthermore, its definition and value depends on whether the scenario is an inadvertent intruder scenario or an accident scenario (see Sections 3.4 and 3.6).

The waste form and package factor (f_w) expresses the resistance of the waste to mobilization by the specific transfer agent initiating the scenario. For example, this factor would be considerably less than unity for waste streams solidified in a matrix and/or packaged in containers that are likely to retain their integrity at the time of inadvertent intrusion. This factor is a property of the waste stream as it is being disposed.

The site selection factor (f_s) depends on many parameters. In some cases, it is proportional to the fraction of a year that the human exposure episode takes place. In other cases, however, (f_s) is also proportional to the release/transport/transfer factor between the biota access locations. For example, for the inadvertent intruder-construction scenario, it is proportional to the transfer factor between contaminated soil and contaminated air.

A brief description of the concentration scenarios is presented below. Specific values of the transfer factors used to calculate impacts are discussed in Section 3 and Reference 1.

Accident Scenario

Nonoccupational acute radiation exposures may result from planned and unplanned releases of material to offsite environs during the operational life of a disposal facility. Planned releases would be addressed on a site-specific basis during the licensing phase of site startup. Two accidental release scenarios can be postulated. One of them involves a postulated breaking open of a waste container and subsequent release of airborne radioactivity, and the second scenario coniders the consequences of a fire igniting in an open disposal trench, with subsequent burning of a portion of the waste and airborne release of combustion products. The comparative severity of these two scenarios depends on various parameters including those associated with the waste form and with site operation.

Construction Scenario

An inadvertent intruder may excavate or construct a building on a disposal site following a breakdown in institutional controls. Under these circumstances, dust will be generated from the application of mechanical forces to the surface materials (soil, rock) through tools and implements (wheels, blades) that pulverize and abrade these materials. The dust particles generated may be then entrained by localized turbulent air currents and can thus become available for inhalation by the intruder. The intruder may also be exposed to direct gamma radiation resulting from airborne particulates and by working directly in the waste-soil mixture. For convenience, this scenario is called the intruder-construction scenario, and appropriate values applicable to typical construction activities are used.

The length of time that the intruder is exposed to radioactivity will be a function of the stability of the waste encountered. If the waste is assumed to be degraded into an unrecognizable form, then it is possible that such construction activities could proceed. However, if the waste is stabilized to the point that the waste mass is clearly distinguishable as something different than ordinary dirt, then it is likely that the inadvertent intruder would stop and investigate. In this case, which can be considered a subset of the intruder-construction scenario and is termed the intruder-discovery scenario, the inadvertent intruder is only exposed during initial discovery of the disposed waste. That is, the same exposure pathways would be involved as for the intruder-construction scenario, but the length of time that the scenario is assumed to occur is reduced.

Agriculture Scenario

In this scenario, an inadvertent intruder is assumed to occupy a dwelling located on the disposal facility and ingest food grown in contaminated soil. (This scenario is assumed to be possible only if the waste has been degraded to an unrecognizable form.) Garden crops may be subject to radionuclide contamination as a result of direct foliar deposition of fallout particulates. Garden crops may also uptake radionuclides via soil-root transfer from contaminated soil. The inadvertent intruder may also be exposed to direct gamma radiation from the naturally suspended radioactivity and from the waste-soil mixture. He may also inhale contaminated air particulates. For convenience, this scenario is called the intruder-agriculture scenario.

2.2.2.4 Total Activity Scenarios

This section considers those release/transport scenarios that are dependent upon the entire activity disposed of at the site. Therefore, all the waste streams disposed at the site contribute to the radionuclide concentrations at the biota access locations. The degree of contribution from a given waste stream is a function of its volume and characteristics (e.g., its form and packaging) and facility design and operating practices (e.g., waste segregation).

All of the total activity scenarios are chronic exposure scenarios (i.e., continuous release and exposure). The equation applicable to the total activity scenarios for each radionuclide is:

$$C_a = \sum_i I_i \times C_{wi} \qquad \text{(G-5)}$$

where (C_a) and (C_{wi}) denote the radionuclide concentrations at the biota access location and in the $(i)^{th}$ waste stream, respectively, and (I_i) is the interaction factor between the $(i)^{th}$ waste stream and the biota access location. The capital sigma indicates that the total radionuclide concentration at the biota access location is a summation of the radioactivity contributed by each waste stream. This summation may also include any potential integration that must be performed due to the areal extent of the disposal site and the areal distribution of the waste streams.

For these scenarios, radioactive concentrations averaged over the time of waste generation and disposal are utilized as a source term (see Appendix D and Reference 6). In other words, the radionuclides in waste streams that are disposed of at the beginning of the disposal site operational period are decayed to the end of the operational period.

The interaction factor (I_i) can generally be expressed through the following equation:

$$I_i = f_o \times f_{di} \times f_{wi} \times f_{si} \quad \text{(G-6)}$$

where subscript i denotes the waste stream, and where:

f_o = time-delay factor (dimensionless);

f_{di} = site design and operation factor (dimensionless);

f_{wi} = waste form and package factor (m^3/yr); and

f_{wi} = site selection factor (yr/m^3);

and where the values of f_{di}, f_{wi} and f_{si} may be functions of the properties of the individual waste streams.

Ground-Water Scenarios

There are several ground-water scenarios depending on the assumed biota access location. One of the access locations is an onsite well which may be drilled and used by a potential inadvertent intruder (intruder-well scenario); another is a well at the boundary of the site which may be utilized by individuals (boundary-well scenario); a third location is a well pumped for common use by a small population some distance away from the disposal facility (population-well scenario); and the fourth location is a stream that receives the discharge from the unconfined ground-water table and which may be used by a larger population (population-surface water scenario). In this appendix, it is assumed that the water table gradient underneath the site is unidirectional, and that a well located at the boundary of the disposal area (rather than the boundary of the site) contributes to the intruder scenarios. This location is more conservative than a well located in the middle of the site since only about half of the potential effluent from the site would contribute to the contamination at a well located in the middle of the site (Ref. 1).

The barrier factors f_{di} and f_{wi} are assumed to be independent of the areal extent of the disposal facility; however, the factor f_{si} represents these areal relationships. The factors f_{di} and f_{wi} and their computations are straightforward, and representative values for these factors are given in Section 3. However, a brief discussion of f_{si} is presented below.

The following general equation is applicable to determine the site selection factor f_{si} (Refs. 2, 3):

$$f_{si} = r_{ti}\, r_g/Q \quad \text{(G-7)}$$

where

Q = dilution factor in units of volume/time;

r_g = dimensionless time-independent reduction factor due to the transverse (perpendicular to the ground-water velocity direction) spatial relationship of the disposal facility with the discharge location; and

r_{ti} = dimensionless reduction factor due to migration and radioactive decay; this factor is dependent on both space and time including the longitudinal (in the direction of the ground-water velocity) spatial relationship of the disposal facility with the discharge location.

The factor Q is independent of the characteristics of the disposal wastes and is also independent of the geometrical relationship of the disposal facility with the discharge location. The factor Q may be the pumping rate of a well or the flow rate of a river. The factors r_g and r_{ti} are discussed in Section 3.5.

Exposed Waste Scenarios

In these scenarios, part or all of the surface area of the disposed waste is assumed to be exposed through some means. The mechanism that initiates uncovering of the waste may be erosion of the waste cover by surface water or wind action, or it may be anthropogenic activities such as farming. Initiating mechanisms related to human activities are examined in the intruder-agriculture and intruder-construction scenarios, and initiating mechanisms related to erosion of the waste cover are examined in Reference 1.

There are two basic exposed waste scenarios depending on whether the transfer agent is wind or surface water. Only population exposures are considered in these scenarios; individual exposures are bounded by the above intruder-construction and intruder-agriculture scenarios. The entire exposed waste area is assumed to be a point source for the impact calculations since the population is assumed to be comparatively distant. The equations and values for the various barrier factors used in the calculations are examined in Section 3.

2.2.2.5 Other Radiological Release/Transport Pathways Considered

A number of other radiological impact release/transport pathways are also considered in this EIS and appendix. These are all short-term pathways related to the management of LLW occurring at locations other than the disposal facility site. Unlike pathways involving releases of radioactive material from a disposal facility, component parts of these release/transport pathways are generally not broken out into the four barrier factors discussed in Section 2.2.2.2. These impact pathways include the following:

- airborne releases from incinerating combustible waste streams at waste generator locations;
- airborne releases from incinerating combustible waste streams at a centralized waste processing facility;

- o population exposures due to transportation of waste to the disposal facility;
- o occupational exposures received during waste processing;
- o occupational exposures received during waste transportation; and
- o occupational exposures received during waste disposal.

Specific values of parameters used to determine the magnitude of impacts from these pathways are presented in Sections 3.8, 4, and 5.

2.3 Other Potential Exposure Pathways

The above release/transport mechanisms are believed to be comparatively the most significant potential pathways to human exposure, and calculational procedures are developed in this appendix to determine potential human exposure levels resulting from these pathways. There are other potential pathways to humans which may be considered during development of performance objectives and technical requirements, but calculational procedures to estimate specific exposure levels were not developed. These potential exposure pathways include the following (Ref. 12):

- o Ground-water migration during the operational period of the facility lifespan;
- o The bathtub effect--filling up of the disposal cells with accumulated leachate and subsequent overflowing;
- o Diffusion of radioisotope tagged decomposition gases through disposal cell covers; and
- o Dispersion of radioactive material by means of surface runoff or wind dispersion from accidentally contaminated site surfaces and equipment.

All of these potential pathways have been observed at DOE-operated and/or commercial disposal facilities (Ref. 12). The first three pathways are fundamentally caused by site instability problems--that is, by degradation of compressive material within a disposal cell and subsequent subsidence of the disposal cell contents, leading to cracking and slumping of disposal cell covers and increased infiltration of rainwater into the disposal cell. At sites with moderate to high permeability soils, an infiltration problem (resulting from a subsidence problem) can lead to migration of some radionuclides being observed during the operational period of the facility life. This would principally involve very mobile radionuclides such as tritium. However, during site operations the potential for ground-water migration would be monitored and if it occurs, the licensee would take steps to correct the situation. Of more concern is the potential long-term migration of all the radionuclides in the waste after site operations have terminated. At sites with very low permeability soils, an infiltration problem can also lead to collection of trench leacnate in disposal cells. This leachate would have to be removed and treated during disposal operations.

It has been demonstrated that potential problems of increased infiltration (migration during the operational period or the bathtub effect) can be minimized or avoided during the operational period through siting or operational procedures. For example, increased attention paid to compaction of disposal trench covers can greatly reduce the maintenance required during site operations. Of more interest from a regulatory point of view is the long-term stability of a disposal facility and methods which may be used to ensure this stability. Impacts from the bathtub effect could ultimately include overland flow of a few to some hundreds of gallons of leachate. The principal impact, however, is likely to be the very high costs of remedial action, which could include pumping, treating, and solidifying leachate, and restabilization of trench covers. This remedial action could result in an expense to a site owner of better than a million dollars per year for a number of years (Ref. 12). Treatment of leachate would involve airborne or waterborne release of radionuclides.

Past disposal experience indicates that potential diffusion of radioisotope-tagged decomposition products is small and can be significantly retarded by facility design and operating practices such as thicker trench covers (Refs. 13, 14). In any case, generation of decomposition gases would be reduced through efforts to minimize the degradation of trench contents. That is, actions undertaken to promote site stability and to minimize or eliminate trench subsidence will also serve to significantly reduce generation of decomposition gases.

Potential operational impacts due to run-off or wind dispersion of contaminated site surfaces are site-specific and would be addressed as part of the licensing of individual disposal facilities, and calculational procedures to estimate the levels of these potential impacts are not developed in this appendix. In any case, these impacts can be reduced to negligible levels through strict onsite contamination control at a disposal facility, and through better attention paid to packaging of wastes for transportation. In the past, one of the most significant contributors to onsite contamination has been accidental spillage of low-level waste liquids which were at one time delivered to some disposal facilities for solidification and disposal, and spillage of trench leachate during pumping for treatment. More recently, however, this practice has been discontinued and all disposal facilities accept only solid wastes for disposal. Probably another cause for onsite contamination is through excessive free-standing liquids in (and leaking out of) disposal containers.

Intrusion by deep-rooted plants or burrowing animals through disposal cell covers is another potential pathway. This intrusion could potentially result in increased human exposures by three general mechanisms: (1) surfacing of radioactive material which could then be dispersed by wind or water, (2) human consumption of contaminated plants or animals, or (3) increasing rainwater percolation into the disposed waste, thereby increasing radionuclide migration through ground water. These potential exposures, particularly the first two mechanisms, are difficult to quantify. Past occurrences of plant and animal intrusion at existing disposal facilities, potential exposure pathways to humans, and methods to reduce or preclude such intrusion are site-specific and would be speculative to quantify in the generic analysis developed in this EIS. In any case, the major impact of deep-rooted plant and burrowing animal intrusion at a disposal facility is likely to be to increase the potential for ground-water migration. This effect is quantitatively considered in this appendix (see Section G.3.5).

2.4 Pathway Dose Conversion Factors

The use of the pathway dose conversion factors (PDCFs) in the calculational methodology is straightforward. It is multiplied by the radionuclide concentration at the biota access location(s) (C_a) to obtain the human exposures:

$$H = PDCF \times C_a \tag{G-1}$$

where PDCF stands for the pathway dose conversion factor in millirem (mrem) per Ci/m^3 for the acute exposure scenarios and in mrem/year per Ci/m^3 for the chronic exposure scenarios. The radionuclide concentration at the biota access location (C_a) is in units of Ci/m^3.

In this work, for acute exposure, H will be taken as the dose in mrem, received during 50 years following a one-year exposure to the radioactive material; and for chronic exposures, H will be taken as the dose rate in mrem/year, received during the 50th year of an exposure period lasting 50 years.

Hereinafter, the qualifier equivalent is assumed to be implicit in the term dose; similarly, the dose equivalent rate will be referred to as the dose rate.

Some of the acute exposure scenarios last for much shorter periods than one year. However, for calculational convenience all acute exposures will be assumed to last one year. A correction factor, used to normalize acute periods to the one-year reference value, will be incorporated into the release/transport portion of the scenario, usually into the site selection factor f_s, as appropriate to the scenario.

2.4.1 Uptake Pathways

The PDCFs for the scenarios discussed in Sections 2.2.2.4 and 2.2.2.5 are the total pathway dose conversion factors for the individual pathways of importance which contribute to human exposures from concentrations of nuclides at biota access locations. The individual pathways that comprise the scenarios are shown in Figure G.3.

As presented in Figure G.3, all of the scenarios involve a secondary biota access location resulting from the primary biota access location. Two of the scenarios have four uptake pathways, four have five, and one has six, yielding a total of 34 uptake pathways. However, of these 34 uptake pathways only 9 are unique types of pathways, if only the uptake mode and transport agents are considered. These nine distinct types of pathways are described in Table G.2.

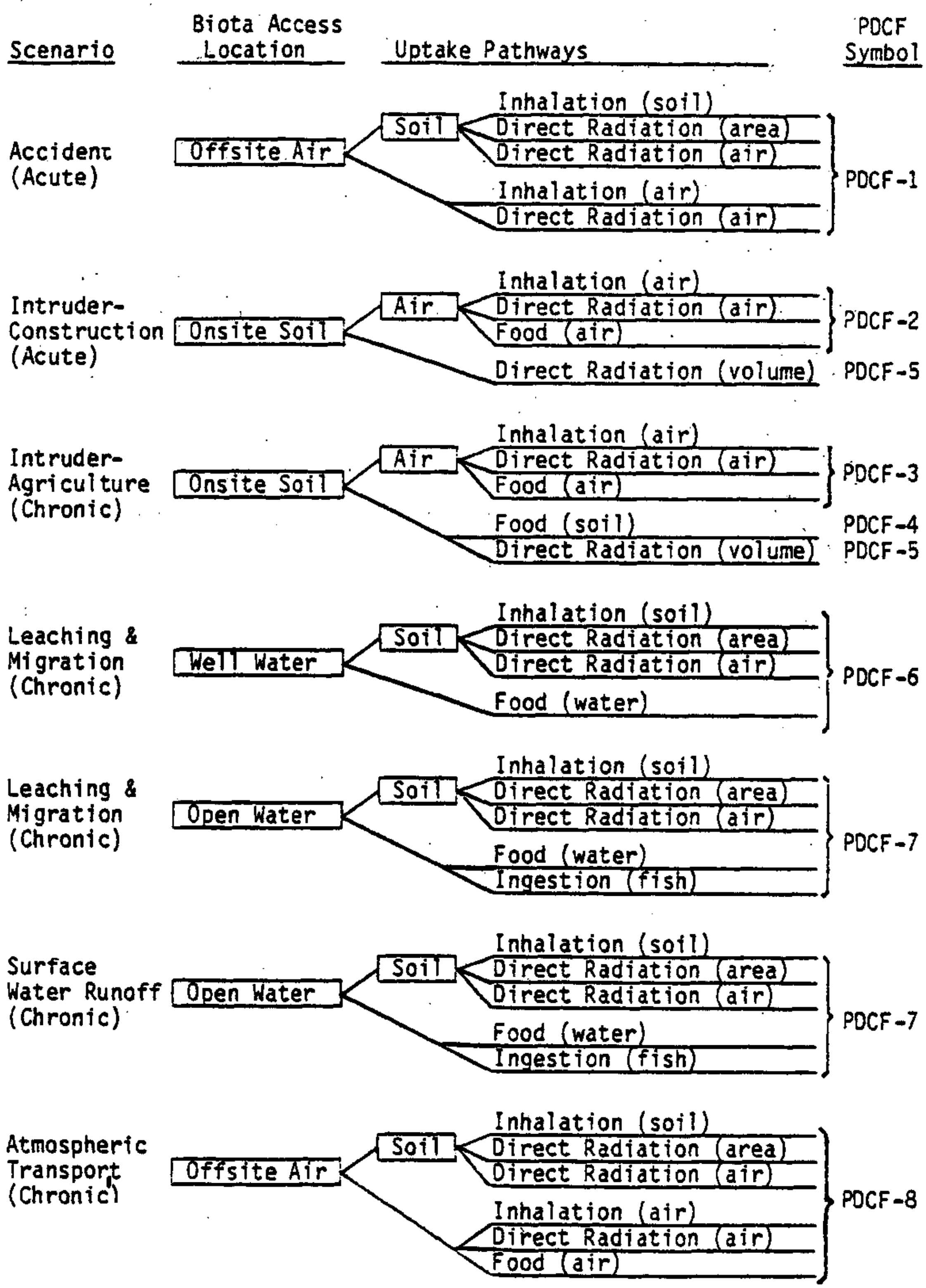


Figure G.3 Details of Uptake Pathways

Table G.2 Access Location-to-Human Pathway Description

Pathway Designation	Description
Food (soil)	This uptake pathway includes a total of three subpathways and denotes uptake of radionuclides originating in plants via soil-to-root transfer from contaminated soil: plant-to-human plant-to-animal-to-human plant-to-animal-to-product-to-human
Food (air)	This uptake pathway includes a total of six subpathways and includes the above three food (soil) subpathways resulting from uptake of radionuclides originating on plant surfaces via deposition from contaminated air and the same three food (soil) subpathways resulting from fallout contamination of the ground.
Food (water)	This uptake pathway includes a total of nine subpathways and includes all the food (soil) pathways resulting from radionuclides originating on plant surfaces via irrigation deposition from contaminated water and from irrigation contamination of the ground. The following three subpathways in addition to plant pathways are added: water-to-human water-to-animal-to-human water-to-animal-to-product-to-human
Ingestion (fish)	Uptake of radionuclides from eating fish caught in contaminated open water.
Inhalation (air)	Uptake of radionuclides from breathing air contaminated due to suspension of contaminated soil particles by human activities.
Inhalation (soil)	Uptake of radionuclides from breathing air contaminated due to natural suspension and volatilization of surface soil.
Direct Gamma (volume)	Direct exposure to gamma rays from standing on ground homogeneously contaminated.
Direct Gamma (area)	Direct exposure to gamma rays from standing on ground whose surface is contaminated.
Direct Gamma (air)	Direct exposure to gamma rays from standing in air homogeneously contaminated.

Only primary and secondary access locations are considered in the determination of these uptake pathways. The effects of possible tertiary access locations, such as air contaminated due to natural suspension radioactivity from soil which is originally contaminated from deposition of radioactivity from air, are not considered. These effects are considered, however, in the selection of transfer factors between the uptake pathways.

The accident scenario includes offsite air as the primary access location leading to two uptake pathways: inhalation (air) and direct gamma (air). It also includes soil contaminated by radionuclide deposition as the secondary access location leading to three more uptake pathways: inhalation (soil), direct gamma (area), and direct gamma (air). Since the exposure period is acute, the food (air) uptake pathway has been excluded from this scenario. However, the direct gamma (air) pathway is included in the secondary access location in addition to the primary access location.

The intruder-construction scenario includes onsite soil as the primary access location and leading to the direct gamma (volume) pathway. The scenario also includes onsite air as the secondary access location leading to three uptake pathways: inhalation (air), direct gamma (air), food (air). Although the exposure period is acute, the food (air) uptake pathway is included with a modification to account for nonequilibrium deposition and root-uptake conditions.

The intruder-agriculture scenario also includes onsite soil as the primary access location; however, the food (soil) uptake pathway is included in this case in addition to the direct gamma (volume) pathway. The scenario also includes onsite air as the secondary access location leading to the same three uptake pathways as the construction scenario secondary access location: inhalation (air), direct gamma (air), and food (air). However, in this case, chronic conditions are assumed to prevail, and equilibrium conditions are assumed for the food (air) uptake pathway.

The next three scenarios involving water are very similar. (The two open water scenarios are identical.) The only additional uptake pathway in the open water scenario as opposed to the well water scenario is the ingestion (fish) pathway. This pathway is included since the bioaccumulation factors for several fish species are significantly greater than unity. However, direct gamma exposure due to immersion in contaminated water was omitted; it turned out to result in negligible additional exposures (less than 0.1%) when compared with the other pathways.

The last scenario, the atmospheric transport scenario, is identical with the accident scenario with the addition of the food (air) uptake pathway to the primary access location. In this case, however, the exposure is assumed to be chronic as opposed to acute for the accident scenario.

A simplified version of Figure G.3 is presented in Figure G.4. The direct gamma (volume) uptake pathway is designated as PDCF-5, and the food (soil) pathway is designated as PDCF-4. Five of the scenarios are represented by a single PDCF. However, the two other scenarios are more complex since different

Figure G.4 Pathway Dose Conversion Factors

Scenario	Biota Access Location		Pathway DCFs
Accident (A)	Offsite Air		PDCF-1
		Air	PDCF-2
Construction (A)	Onsite Soil		PDCF-5
		Air	PDCF-3
Agriculture (C)	Onsite Soil		PDCF-4 PDCF-5
Leaching and Migration (C)	Well Water		PDCF-6
Leaching and Migration (C)	Open Water		PDCF-7
Surface Water Runoff (C)	Open Water		PDCF-7
Atmospheric Transport (C)	Offsite Air		PDCF-8

transfer factors are applicable to the individual components of the intruder-construction and intruder-agriculture scenarios. The differences in the transfer factors result from either differences in the mechanism mobilizing the radioactivity or differences in the access locations.

2.4.2 Pathway Dose Conversion Factor Tables

Seven human organs are considered in this EIS for each radionuclide and each pathway: total body, bone, kidney, thyroid, liver, lung, and gastrointestinal (GI) tact. These pathway dose conversion factors (PDCFs) have been derived from the 9 independent pathways presented in Table G.2. The information utilized to calculate the PDCFs includes human physiological parameters (e.g., breathing rates, nuclide metabolism), dietary intakes, and nuclide-specific food chain transfer rates (Ref. 1).

All the PCDFs are calculated based on five sets of fundamental dose conversion factors. Two of the sets include DCFs for determining the inhalation 50-year committed dose in units of mrem per pCi inhaled and the ingestion 50-year committed dose in units of mrem per pCi ingested. Three different gamma radiation exposure DCFs are used depending on the biota access location which can be either in-depth soil contamination (mrem/year per $pCim^3$), surface soil contamination (mrem/year per pCi/m^2), or air contamination (mrem/year per pCi/m^3). These fundamental DCFs depend on the radionuclides of concern and the organ receiving the dose. A brief description of the fundamental DCFs is provided below.

The complete lung model, as proposed by the ICRP Task Group on Lung Dynamics (Refs. 15, 16) has been utilized in this appendix for the calculation of the fundamental inhalation dose conversion factors. This model permits a more realistic calculation of radiation dose to the human respiratory tract from inhaled radioactivity than does the initial ICRP lung model (Ref. 17). For the fundamental ingestion DCFs, DCFs given in Regulatory Guide 1.109 (Ref. 18) and NUREG-0172 (Ref. 19) have been utilized in this EIS.

The need to use three different fundamental direct gamma exposure DCFs arises from the geometry of exposure, and the attenuation and buildup afforded by the different contaminated media. In this EIS, fundamental direct gamma (volume) DCFs have been calculated based on the equations presented in Reference 20 and the emitted gamma energy characteristics of the radionuclides considered (Ref. 21). For the fundamental direct gamma (area) and the direct gamma (air) DCFs (which include exposure to electron radiation as well), the tables given in Reference 23 are utilized. The PDCFs calculated based on these fundamental dose conversion factors and pathway uptake factors (Ref. 1) are presented in Tables G.3 through G.10.

The I-129 PDCF for thyroid requires further discussion. The calculated I-129 PDCFs do not take into account the dilution of I-129 with natural iodine. Experimental environmental data and theoretical calculations (Ref. 1) have led some investigators in the past to utilize the total body dose to humans as a better indicator of the limiting exposure due to I-129 than the thyroid dose (Ref. 23). This selection results in a significant difference in limiting exposures since the fundamental dose conversion factors for thyroid are about 1000 times those for the total body (see Tables G.3 through G.10). However, a correction to the calculated thyroid PDCFs to account for dilution of I-129 with natural iodine has not been made in this appendix.

3. DISPOSAL IMPACTS

This section presents the calculational procedures utilized to determine the impact measures associated with the disposal of LLW. These impact measures include individual and population exposures, occupational exposures, costs, energy use, and land use.

The impact measures are strongly dependent on the waste form and package properties (Appendix D), and disposal facility environment, design, and operating practices (Appendices E and F). Accordingly, Section 3.1 presents the background assumptions regarding the disposal technology alternatives considered, and discusses how these assumptions are incorporated into the impact calculations. Similarly, Section 3.2 presents procedures through which the effects of waste form and packaging are incorporated into the calculations.

Following these two background sections, Sections 3.3 through 3.7 present the equations and specific parameter values used to calculate individual and population exposures for the applicable scenarios considered in Section 2.2.

Table G.3 Pathway Dose Conversion Factor - 1

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	1.25E+09	5.19E+07	1.25E+09	1.25E+09	1.25E+09	1.25E+09	5.19E+07
C-14	3.17E+09	1.40E+10	3.17E+09	3.17E+09	3.17E+09	3.17E+09	2.53E+09
FE-55	1.81E+10	1.89E+10	2.41E+10	1.61E+10	1.61E+10	2.08E+11	1.93E+10
CO-60	2.36E+12	2.34E+12	2.35E+12	2.34E+12	2.34E+12	2.63E+13	2.50E+12
NI-59	3.70E+10	9.38E+10	5.06E+10	2.58E+10	2.58E+10	5.78E+10	2.85E+10
NI-63	3.06E+10	9.60E+11	6.58E+10	1.56E+08	1.56E+08	8.82E+10	7.44E+09
SR-90	2.42E+13	9.62E+13	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.89E+11
NB-94	6.10E+11	6.11E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	6.28E+11
TC-99	1.18E+09	9.68E+08	2.28E+09	7.60E+08	2.00E+10	7.40E+09	7.88E+09
I-129	9.14E+11	8.52E+11	8.52E+11	5.13E+13	8.52E+11	8.57E+11	8.52E+11
CS-135	2.37E+10	9.65E+10	8.85E+10	5.08E+08	3.33E+10	1.49E+10	1.00E+09
CS-137	4.50E+11	6.34E+11	7.78E+11	2.42E+11	4.26E+11	3.30E+11	2.44E+11
U-235	2.06E+12	3.06E+13	2.21E+11	2.21E+11	7.26E+12	3.36E+15	5.17E+11
U-238+D	1.69E+12	2.88E+13	1.45E+10	1.45E+10	6.57E+12	3.12E+15	2.55E+11
NP-237+D	5.20E+14	1.20E+16	1.12E+15	1.34E+11	3.84E+15	3.60E+14	3.74E+11
PU-238	2.00E+14	4.08E+15	2.80E+15	1.92E+10	8.80E+14	4.08E+15	3.31E+11
PU-239	2.24E+14	4.80E+15	3.12E+15	7.40E+09	9.60E+14	3.84E+15	3.03E+11
PU-241	3.04E+12	7.44E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	5.57E+09
PU-242	2.16E+14	4.48E+15	3.04E+15	1.44E+10	9.60E+14	3.68E+15	2.94E+11
AM-241	5.04E+14	7.12E+15	6.64E+15	7.87E+10	3.84E+15	4.24E+14	3.59E+11
AM-243	4.96E+14	7.04E+15	6.48E+15	9.10E+10	3.76E+15	4.00E+14	3.63E+11
CM-243	3.84E+14	6.16E+15	5.60E+15	2.44E+11	1.76E+15	4.40E+14	5.48E+11
CM-244	2.80E+14	4.40E+15	4.16E+15	1.71E+10	1.28E+15	4.40E+14	3.05E+11

Table G.4 Pathway Dose Conversion Factor - 2

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	1.17E+10	5.19E+07	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.05E+10
C-14	6.68E+10	3.32E+11	6.68E+10	6.68E+10	6.68E+10	6.68E+10	6.61E+10
FE-55	9.28E+09	4.28E+10	3.94E+10	5.08E+07	5.08E+07	2.10E+11	2.12E+10
CO-60	1.24E+11	2.28E+10	7.60E+10	2.28E+10	2.28E+10	2.40E+13	8.59E+11
NI-59	3.87E+10	2.33E+11	8.13E+10	5.98E+07	5.98E+07	3.21E+10	1.44E+10
NI-63	1.04E+11	3.15E+12	2.18E+11	1.56E+08	1.56E+08	8.82E+08	3.91E+10
SR-90	5.52E+13	2.23E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	3.69E+12
NB-94	1.39E+10	1.51E+10	1.45E+10	1.32E+10	1.45E+10	7.33E+11	4.43E+11
TC-99	2.25E+09	3.64E+09	6.26E+09	7.60E+08	7.00E+10	7.74E+09	1.38E+11
I-129	2.00E+12	6.88E+11	5.91E+11	1.57E+15	1.27E+12	6.37E+09	9.45E+10
CS-135	1.57E+11	4.21E+11	3.88E+11	5.08E+08	1.47E+11	4.89E+10	8.01E+09
CS-137	1.40E+12	1.72E+12	2.35E+12	1.53E+09	8.01E+11	2.94E+11	3.92E+10
U-235	2.64E+12	4.36E+13	1.59E+09	1.59E+09	1.01E+13	3.36E+15	1.59E+12
U-238+D	2.43E+12	4.15E+13	8.57E+07	8.57E+07	9.45E+12	3.12E+15	1.15E+12
NP-237+D	5.21E+14	1.20E+16	1.12E+15	8.40E+08	3.85E+15	3.60E+14	1.55E+12
PU-238	2.00E+14	4.09E+15	2.80E+15	8.87E+07	8.81E+14	4.08E+15	1.51E+12
PU-239	2.24E+14	4.81E+15	3.12E+15	5.17E+07	9.61E+14	3.84E+15	1.39E+12
PU-241	3.05E+12	7.47E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	2.86E+10
PU-242	2.16E+14	4.49E+15	3.04E+15	6.93E+07	9.61E+14	3.68E+15	1.35E+12
AM-241	5.05E+14	7.13E+15	6.64E+15	3.80E+08	3.85E+15	4.24E+14	1.51E+12
AM-243	4.97E+14	7.05E+15	6.48E+15	6.09E+08	3.77E+15	4.00E+14	1.71E+12
CM-243	3.85E+14	6.17E+15	5.60E+15	2.26E+09	1.76E+15	4.40E+14	1.59E+12
CM-244	2.80E+14	4.41E+15	4.16E+15	7.23E+07	1.28E+15	4.40E+14	1.53E+12

Table G.5 Pathway Dose Conversion Factor - 3

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	4.45E+10	5.19E+07	4.45E+10	4.45E+10	4.45E+10	4.45E+10	4.35E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	3.22E+10	1.90E+11	1.38E+11	5.08E+07	5.08E+07	2.64E+11	7.75E+10
CO-60	3.70E+11	2.28E+10	1.87E+11	2.28E+10	2.28E+10	2.40E+13	2.95E+12
NI-59	1.25E+11	7.48E+11	2.58E+11	5.98E+07	5.98E+07	3.21E+10	5.08E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	1.52E+13
NB-94	1.40E+10	1.55E+10	1.47E+10	1.32E+10	1.46E+10	7.33E+11	1.56E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	8.06E+12	2.84E+12	2.44E+12	6.33E+15	5.24E+12	6.37E+09	3.87E+11
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.12E+12	5.87E+12	8.03E+12	1.53E+09	2.73E+12	9.35E+11	1.49E+11
U-235	5.15E+12	8.50E+13	1.59E+09	1.59E+09	1.98E+13	3.36E+15	5.62E+12
U-238+D	4.77E+12	8.11E+13	8.57E+07	8.57E+07	1.85E+13	3.12E+15	3.99E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	8.40E+08	3.87E+15	3.60E+14	5.65E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	8.87E+07	8.85E+14	4.08E+15	5.28E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	5.17E+07	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+13	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	6.93E+07	9.65E+14	3.68E+15	4.72E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	3.80E+08	3.87E+15	4.24E+14	5.36E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	6.09E+08	3.79E+15	4.00E+14	6.22E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.26E+09	1.77E+15	4.40E+14	5.63E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	7.23E+07	1.29E+15	4.40E+14	5.43E+12

Table G.6 Pathway Dose Conversion Factor - 4

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	5.99E+04	0.	5.99E+04	5.99E+04	5.99E+04	5.99E+04	5.99E+04
C-14	3.72E+05	1.86E+06	3.72E+05	3.72E+05	3.72E+05	3.72E+05	3.72E+05
FE-55	3.48E+01	2.16E+02	1.49E+02	0.	0.	8.33E+01	8.57E+01
CO-60	5.27E+03	0.	2.39E+03	0.	0.	0.	4.49E+04
NI-59	3.69E+03	2.21E+04	7.59E+03	0.	0.	0.	1.56E+03
NI-63	9.88E+03	2.95E+05	2.04E+04	0.	0.	0.	4.26E+03
SR-90	3.76E+06	1.53E+07	0.	0.	0.	0.	4.42E+05
NB-94	2.12E+00	7.08E+00	3.94E+00	0.	3.89E+00	0.	2.39E+04
TC-99	1.53E+03	3.82E+03	5.68E+03	0.	7.15E+04	4.83E+02	1.86E+05
I-129	2.19E+04	7.77E+03	6.68E+03	1.72E+07	1.44E+04	0.	1.06E+03
CS-135	9.50E+03	2.32E+04	2.14E+04	0.	8.10E+03	2.43E+03	5.01E+02
CS-137	8.49E+04	9.48E+04	1.30E+05	0.	4.40E+04	1.46E+04	2.51E+03
U-235	1.44E+04	2.38E+05	0.	0.	5.55E+04	0.	2.32E+04
U-238+D	1.35E+04	2.28E+05	0.	0.	5.20E+04	0.	1.63E+04
NP-237+D	1.64E+04	4.07E+05	3.53E+04	0.	1.22E+05	0.	2.36E+04
PU-238	1.14E+03	4.52E+04	6.37E+03	0.	4.87E+03	0.	4.85E+03
PU-239	1.27E+03	5.23E+04	7.05E+03	0.	5.39E+03	0.	4.43E+03
PU-241	2.21E+01	1.10E+03	5.61E+01	0.	1.02E+02	0.	9.31E+01
PU-242	1.22E+03	4.85E+04	6.78E+03	0.	5.19E+03	0.	4.34E+03
AM-241	3.60E+04	5.45E+05	1.92E+05	0.	2.71E+05	0.	4.94E+04
AM-243	3.53E+04	5.44E+05	1.85E+05	0.	2.65E+05	0.	5.79E+04
CM-243	1.11E+04	1.90E+05	7.15E+04	0.	5.20E+04	0.	2.32E+04
CM-244	8.52E+03	1.43E+05	6.15E+04	0.	3.98E+04	0.	2.24E+04

Table G.7 Pathway Dose Conversion Factor - 5

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	0.	0.	0.	0.	0.	0.	0.
C-14	0.	0.	0.	0.	0.	0.	0.
FE-55	0.	0.	0.	0.	0.	0.	0.
CO-60	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07
NI-59	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03
NI-63	0.	0.	0.	0.	0.	0.	0.
SR-90	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04
NB-94	9.63E+06	9.63E+06	9.63E+09	9.63E+06	9.63E+06	9.63E+06	9.63E+06
TC-99	0.	0.	0.	0.	0.	0.	0.
I-129	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04
CS-135	0.	0.	0.	0.	0.	0.	0.
CS-137	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06
U-235	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05
U-238+D	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03
NP-237+D	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.55E+04	6.56E+04
PU-238	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01
PU-239	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01
PU-241	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04
AM-243	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05
CM-243	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05
CM-244	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01

Table G.8 Pathway Dose Conversion Factor - 6

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	1.44E+07	7.21E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07
FE-55	2.73E+06	1.24E+07	8.86E+06	8.61E+05	8.61E+05	5.33E+06	5.45E+06
CO-60	1.43E+08	1.24E+08	1.33E+08	1.24E+08	1.24E+08	1.24E+08	2.89E+08
NI-59	8.54E+06	4.42E+07	1.61E+07	1.38E+06	1.38E+06	1.38E+06	4.41E+06
NI-63	1.92E+07	5.71E+08	3.96E+07	4.28E-01	4.28E-01	2.42E+02	8.26E+06
SR-90	7.61E+09	3.10E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.04E+08
NB-94	3.19E+07	3.20E+07	3.19E+07	3.19E+07	3.19E+07	3.19E+07	1.47E+08
TC-99	3.60E+05	8.96E+05	1.33E+06	2.08E+00	1.68E+07	1.13E+05	4.36E+07
I-129	4.18E+07	1.72E+07	1.53E+07	2.99E+10	2.87E+07	3.64E+06	5.48E+06
CS-135	3.32E+07	8.09E+07	7.47E+07	1.39E+00	2.83E+07	8.46E+06	1.75E+06
CS-137	3.09E+08	3.44E+08	4.65E+08	1.29E+07	1.66E+08	6.39E+07	2.16E+07
U-235	2.07E+08	3.24E+09	1.18E+07	1.18E+07	7.64E+08	2.10E+07	3.26E+08
U-238+D	1.83E+08	3.09E+09	7.74E+05	7.74E+05	7.05E+08	9.32E+06	2.22E+08
NP-237+D	2.31E+08	5.55E+09	4.88E+08	7.13E+06	1.67E+09	8.11E+06	3.26E+08
PU-238	7.02E+07	2.74E+09	3.93E+08	1.03E+06	2.97E+08	1.22E+07	2.94E+08
PU-239	7.77E+07	3.17E+09	4.34E+08	3.93E+05	3.28E+08	1.09E+07	2.68E+08
PU-241	1.34E+06	6.64E+07	3.51E+06	1.31E-01	6.18E+06	1.86E+04	5.62E+06
PU-242	7.52E+07	2.94E+09	4.18E+08	7.67E+05	3.17E+08	1.09E+07	2.63E+08
AM-241	2.25E+08	3.34E+09	1.19E+09	4.19E+06	1.66E+09	5.35E+06	3.05E+08
AM-243	2.21E+08	3.34E+09	1.15E+09	4.84E+06	1.63E+09	5.93E+06	3.57E+08
CM-243	1.65E+08	2.60E+09	9.97E+08	1.30E+07	7.21E+08	1.42E+07	3.27E+08
CM-244	1.17E+08	1.95E+09	8.44E+08	9.09E+05	5.43E+08	2.12E+06	3.04E+08

Table G.9 Pathway Dose Conversion Factor - 7

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	3.76E+07	1.88E+08	3.76E+07	3.76E+07	3.76E+07	3.76E+07	3.76E+07
FE-55	4.45E+06	2.31E+07	1.63E+07	8.61E+05	8.61E+05	9.45E+06	9.69E+06
CO-60	1.46E+08	1.24E+08	1.34E+08	1.24E+08	1.24E+08	1.24E+08	3.11E+08
NI-59	9.82E+06	5.20E+07	1.87E+07	1.38E+06	1.38E+06	1.38E+06	4.95E+06
NI-63	2.26E+07	6.74E+08	4.67E+07	4.28E-01	4.28E-01	2.42E+02	9.74E+06
SR-90	8.18E+09	3.33E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.71E+08
NB-94	3.23E+07	3.32E+07	3.27E+07	3.19E+07	3.26E+07	3.19E+07	4.50E+09
TC-99	3.65E+05	9.09E+05	1.35E+06	2.08E+00	1.70E+07	1.15E+05	4.42E+07
I-129	4.28E+07	1.75E+07	1.56E+07	3.07E+10	2.93E+07	3.64E+06	5.53E+06
CS-135	1.44E+08	3.52E+08	3.25E+08	1.39E+00	1.23E+08	3.68E+07	7.60E+06
CS-137	1.30E+09	1.45E+09	1.98E+09	1.29E+07	6.81E+08	2.35E+08	5.09E+07
U-235	2.11E+08	3.29E+09	1.18E+07	1.18E+07	7.78E+08	2.10E+07	3.32E+08
U-238+D	1.87E+08	3.14E+09	7.74E+05	7.74E+05	7.18E+08	9.32E+06	2.26E+08
NP-237+D	2.57E+08	6.19E+09	5.44E+08	7.13E+06	1.87E+09	8.11E+06	3.63E+08
PU-238	7.49E+07	2.93E+09	4.19E+08	1.03E+06	3.17E+08	1.22E+07	3.14E+08
PU-239	8.29E+07	3.39E+09	4.63E+08	3.93E+05	3.51E+08	1.09E+07	2.86E+08
PU-241	1.43E+06	7.09E+07	3.74E+06	1.31E-01	6.60E+06	1.86E+04	6.00E+06
PU-242	8.02E+07	3.14E+09	4.46E+08	7.67E+05	3.38E+08	1.09E+07	2.81E+08
AM-241	3.72E+08	5.57E+09	1.97E+09	4.19E+06	2.77E+09	5.35E+06	5.07E+08
AM-243	3.65E+08	5.57E+09	1.91E+09	4.84E+06	2.72E+09	5.93E+06	5.94E+08
CM-243	2.09E+08	3.35E+09	1.28E+09	1.30E+07	9.26E+08	1.42E+07	4.18E+08
CM-244	1.51E+08	2.52E+09	1.09E+09	9.09E+05	7.00E+08	2.12E+06	3.93E+08

Table G.10 Pathway Dose Conversion Factor - 8

Isotope	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	4.45E+10	5.19E+07	4.52E+10	4.45E+10	4.45E+10	4.45E+10	4.33E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	4.83E+10	2.06E+11	1.54E+11	1.61E+10	1.61E+10	2.80E+11	9.36E+10
CO-60	2.68E+12	2.34E+12	2.50E+12	2.34E+12	2.34E+12	2.63E+13	5.27E+12
NI-59	1.50E+11	7.73E+11	2.84E+11	2.58E+10	2.58E+10	5.78E+10	7.65E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+11	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.53E+13
NB-94	6.10E+11	6.12E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	2.15E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	8.91E+12	3.69E+12	3.29E+12	6.33E+15	6.10E+12	8.57E+11	1.24E+12
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.36E+12	6.12E+12	8.27E+12	2.42E+11	2.97E+12	1.18E+12	3.90E+11
U-235	5.37E+12	8.52E+13	2.21E+11	2.21E+11	2.00E+13	3.36E+15	5.84E+12
U-238+D	4.79E+12	8.11E+13	1.45E+10	1.45E+10	1.85E+13	3.12E+15	4.00E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	1.34E+11	3.87E+15	3.60E+14	5.79E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	1.92E+10	8.85E+14	4.08E+15	5.30E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	7.40E+09	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+15	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	1.44E+10	9.65E+14	3.68E+15	4.74E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	7.87E+10	3.87E+15	4.24E+14	5.43E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	9.10E+10	3.79E+15	4.00E+14	6.31E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.44E+11	1.77E+15	4.40E+14	5.87E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	1.71E+10	1.29E+15	4.40E+14	5.45E+12

Finally, Section 3.8 details the calculation of other impact measures considered in this appendix, including occupational exposures, land use, disposal costs, and energy use. The reference near-surface disposal facility, which was constructed to illustrate the concepts mentioned in this environmental impact statement, is discussed in Appendix E.

3.1 Disposal Technology Indices

In order to analyze the impacts from disposal of LLW, alternative disposal technology properties and their effect on the impact measure calculations must be quantified. For example, depending on specific operational procedures such as random or stacked disposal, the values of the barrier factors presented in Section 2.2 vary. In this appendix, the disposal technology properties have been expressed in the form of integer indices that refer to a specific procedure on the barrier factor computations or determine a specific value of the environmental parameters. These indices, which will be referred to as the disposal technology indices, basically denote the selection options available for a specific property. These selection options may be in the form of a specific calculation procedure or a specific value for an environmental property.

The primary rationale for handling the variations in the disposal technology properties in this manner is to provide flexibility in updating the information base associated with the alternative disposal technologies. Each value of these indices imply a value for the corresponding disposal technology property; these property values may be altered and updated with ease without changing the values of the indices or the structure of the calculations.

The disposal technology properties that have been considered in the calculation of impacts in this report are summarized in Table G.11.

3.1.1 Region Index--IR

This index, whose value is 1 or higher, is set depending upon the region considered and determines use of a specific set of environmental properties in the impact calculations. The main effect of the region index is on the site selection factor. Environmental properties that are dependent on the region index are presented in Table G.12.

The value of this index corresponding to each of the regions is as follows:

- o IR=1: Northwest region
- o IR=2: Southeast region
- o IR=3: Midwest region
- o IR=4: West region

In this EIS, the southeastern region is used for the reference disposal facility site. Variations on the values assigned for the regions (e.g., to perform sensitivity analyses) can also be triggered through use of the region index.

Table G.11 Disposal Technology Indices

Property and Index		Description
Region	- IR	Geographic location of the disposal facility.
Design	- ID	Two options are considered: regular trenches, and the so-called "concrete-walled" trenches.
Cover	- IC	Three options on the cover between the waste and the atmosphere are considered: regular, thick, and intruder barrier.
Emplacement	- IE	Three options on the emplacement of the waste are considered: random, stacked, and random combined with decontainerized disposal for compressible low activity wastes
Stabilization	- IX	Three options on the stabilization program applied to disposal cells, which may contain structurally unstable wastes, are considered: regular, moderate, and extensive.
Layering	- IL	Option on separating and putting selected waste streams (usually with higher external radiation levels) at the bottom of the disposal cell.
Segregation	-IS	Option to segregate and separately dispose of wastes that are combustible/compressible and those that could contain complexing agents.
Grouting	- IG	Option on filling of the interstitial spaces between the wastes with grouting material.
Hot Waste Facility	- IH	Option on having a special area within the disposal facility with special procedures to handle high activity wastes.
Closure Index	- IQ	This index indicates the activities during the closure period (regular or extensive).
Care Level Index	- ICL	This index indicates the care level anticipated during the active institutional control period (low, moderate, and high).
Postopertional Period (Years)	- IPO	Duration of the period between the cessation of active disposal and the transfer of the title from the site operator to the site owner.
Institutional Control Period (Years)	- IIC	Duration between transfer of the title to the site owner and the assumed time for loss of institutional controls over the site.

Table G.12 Region Index Dependent Properties

Symbol	Scenario	Environmental Property
TPO	Accident	Air-to-air transfer factor
FSC	Construction	Soil-to-air transfer factor
FSA	Agriculture	Soil-to-air transfer factor
QFC	Ground water	Dilution factor
TTM	Ground water	Water travel time
DTTM	Ground water	Incremental water travel time
TPC	Ground water	Peclet number
DTPB	Ground water	Incremental peclet number
RGF	Ground water	Factor r_g
RET	Ground water	Retardation coefficients
PRC	Ground water	Infiltrating percolation
POP	Exposed Waste	Air-to-air and surface water transfer factors
DIST	Transportation	One-way travel distance
STPS	Transportation	Number of stops per trip
CASK	Transportation	Cask days per round trip

3.1.2 Design and Operation Index

There are four design and operation indices: design index--ID; cover index--IC; emplacement index--IE; and stabilization index--IX. The values of these indices are 1 or higher denoting the options available in the design of the disposal facility; details of the options can be found in Appendices E and F. These indices are considered below.

The Design Index--ID characterizes the disposal unit design used for radioactive waste disposal. Two options have been used in this study: regular trench disposal and concrete-walled trench disposal. This index primarily affects the site design factor.

In this appendix, three different "efficiencies" are utilized to describe the specific procedures employed in the disposal of wastes:

- the volumetric disposal efficiency which is defined as the volume of disposal space available in the disposal cell (in m^3) per unit surface area (in m^2) of the disposal cell,

- the emplacement efficiency which is the volume of waste emplaced in the disposal cell (in m^3) per unit volume (in m^3) of available disposal space, and

- the surface efficiency which is defined as the ratio of the surface area occupied by the disposal cells to the surface area occupied by the disposal cells plus the surface area between these cells that have not been utilized for disposal.

The design index determines the volumetric disposal efficiency and the surface efficiency of the design. The emplacement efficiency is discussed below. Use of a hot waste facility (see Section 3.1.3), which is defined as a special group of disposal cells used for disposal of high-activity waste, is not included in the above definitions; its efficiencies are assumed to be independent of the design index.

The Cover Index--IC can be either 1, 2, or 3, and it denotes whether a "regular" cover (denoted by 1), a "thick" cover (denoted by 2), or an engineered "intruder barrier" cover (denoted by 3) is placed over the disposed waste. A regular cover refers to 1 meter of fill below the existing grade plus a minimum of 1 meter cover above grade. A thick cover refers to the same 1 m of fill below the existing grade plus a 2-meter thick engineered cover constructed of compacted high quality clay to minimize infiltration of percolation. An engineered intruder barrier refers to the same 1 meter of fill below the existing grade plus a minimum of 5-meter thick engineered cover (e.g., low permeability layers, interbedded sand/gravel/boulder layers) to minimize infiltration and preclude intrusion.

The Emplacement Index--IE denotes the specific method used to emplace the waste in the disposal cells and primarily affects the site design factor. The three options considered and associated emplacement efficiencies are discussed below.

Random emplacement (option 1) involves simply dumping the waste directly into the disposal cell. It is the fastest method which can be used, and therefore leads to the lowest occupational exposures. However, random emplacement of waste containers may be accomplished with only about 50% emplacement efficiency (one-half the available space is empty or filled with earth or other material), and there is a higher probability of the occurrence of accidents as well as container damage during haphazard dumping.

Stacked emplacement (option 2) involves stacking waste containers in neat piles, using cranes, forklifts, etc., to accomplish this. This case may be difficult to achieve on a routine basis but represents the maximum practical volume utilization. In this case, the potential for accidents and waste container damage is much lower, and approximately 75% of the available disposal space is used--i.e., the emplacement efficiency is 0.75. However, additional fuel must be used to operate the heavy equipment used for emplacement, and occupational doses increase as more men must spend more time near the disposed waste.

Decontainerized emplacement (option 3) involves randomly disposing of all structurally stable and/or higher activity wastes, and decontainerizing and disposing low activity wastes that are, over the long term, structurally unstable. In this case, the disposal facility would be operated somewhat like a sanitary landfill. This option can substantially reduce disposal cell instability problems by accelerating the compression of unstable wastes. However, it requires a significantly increased effort by the site operator and leads to higher occupational exposures (see Appendix F). The emplacement efficiency of this option is estimated to be about 0.5 since part of the waste containers are randomly emplaced and additional soil between wastes is likely to be required during emplacement of decontainerized wastes.

The Stabilization Index--IX, whose value can be 1, 2, or 3, denotes the extent to which the disposal cells are stabilized. Such stabilization measures may be implemented during disposal operations. Past disposal experience indicates that the difficulties currently experienced at several existing disposal sites may have resulted from the natural compaction and decomposition of the wastes leading to subsidence of the disposal cell cover and increased rainwater percolation. A stabilization program with no special compaction procedures other than the use of the weight of trucks or heavy equipment is denoted by 1. A more extensive stabilization program involving sheeps-foot rollers and/or vibratory compaction during operations is denoted by 2. A program involving very extensive techniques such as dynamic compaction or similar measures is denoted by 3. This option affects the site design factor and the waste form and package factor.

3.1.3 Site Operational Options

Four operational options which may be exercised in the design of the disposal facility are considered: layering--IL, segregation--IS, grouting--IG, and use of a hot waste facility--IH. The values of all these indices are either 0, signifying that the option has not been exercised, or 1, signifying that the option has been implemented in the design. These options are briefly discussed below.

Layering Option--IL denotes whether selected waste streams (usually those with higher external radiation levels) are separated and disposed of at the bottom of the disposal cells. This practice is frequently implemented at the existing sites to minimize occupational exposures. This option, however, affects the site design factor sigificantly by limiting access of potential inadvertent intruders to the layered waste streams.

Segregation Option--IS indicates whether, during the disposal operations, the wastes are segregated and disposed of in separate disposal cells based on their compressibility/combustibility and whether they contain radionuclide-complexing chemical agents. Implementing the segregation option increases the performance capability of the disposal cell covers by limiting expected long-term waste degradation and compression after disposal to those cells containing unstable wastes. It also limits the effects of chemicals that may increase radionuclide mobility to those wastes containing these chemicals. This index primarily affects the ground-water scenario through the site design factor and the waste form factor.

Grouting Option--IG indicates whether the interstitial spaces between the waste packages are filled with a material that will improve disposal cell stability. During the grouting operation, as each layer of waste is emplaced in the disposal cell, pumpable concrete (grout) is pumped to fill all interstitial spaces between the waste containers. Some grout is also placed under the lowest layer of waste and on top of the total waste mass. Grouting is expensive, but its use is advantageous in that the waste is totally encapsulated and immobilized. There is little opportunity for infiltrating precipitation to contact the waste; the grout provides stability, and potential long-term migrational and intruder impacts are minimized. This option affects the site design factor and the waste form factor.

Hot Waste Facility Option--IH indicates use of specially designed disposal cells utilizing special operational procedures to dispose of certain high-activity waste streams. In this appendix, if a hot waste facility is used, it is located at the center of the disposal facility. Confinement of the wastes and limiting their interaction with transport agents such as wind and water are the primary considerations in hot waste facility design, and other factors such as costs and surface efficiency are secondary design objectives. Consequently, the hot waste facility represents an "idealized" confinement concept which is nonetheless achievable utilizing existing disposal technology. Various example "hot waste facility designs" are considered in Appendix F; however, to compute hot waste facility costs in this appendix, it is assumed to be a concrete-walled trench into which the waste is stacked and grouted in place. A concrete cover is then poured over the emplaced waste.

3.1.4 Postoperational Indices

There are four postoperational indices: closure index--IQ, care level index--ICL, postoperational period--IPO, and active institutional control period--IIC. These are considered below.

The Closure Index--IQ, whose value can be 1 or 2, refers to actions implemented during the closure period after the cessation of disposal operations and prior to the transfer of the site title to the site owner. An index value of 1 indicates that closure operations are assumed to last two years and involve a relatively modest level of effort by the facility operator. Closure operations are assumed to consist of dismantlement and decontamination of site buildings (except those necessary for the site owners during the active institutional control period), disposal of wastes generated during the dismantlement and decontamination operations, final contouring (including implementation of final surface drainage systems) and vegetation of the site, final radiation surveys, etc. An index value of 2 indicates that a complete site restabilization program is carried out at site closure in addition to other closure operations discussed above. This program, which is assumed to increase the closure period to four years, is intended to enhance the integrity of the disposal cell covers and therefore reduce the amount of water potentially infiltrating into the disposal cells. The restabilization program involves: (1) stripping off the existing cell covers, (2) use of vibratory compaction or similar measures to accelerate disposal cell compression, (3) backfilling the resultant compressed areas, (4) reconstruction of the cell covers, and (5) revegetation of the covers. Implementation of these measures is assumed to be equivalent to the implementation of a stabilization program during disposal operations corresponding to an IX value of 2.

The Care Level Index--ICL, whose value can be 1, 2, or 3, refers to activities during the active institutional control period that are implemented by the site owner. Different measures may have to be implemented depending on operational parameters such as the stabilization program, whether the segregation option has been implemented, the type of disposal cell covers utilized, etc.

The level of care may range from routine surveillance and maintenance of the disposal facility (e.g., cutting the grass) which would not include any major active maintenance such as major cover engineering (low-care level denoted by 1) to extensive stabilization and remedial programs similar to those being implemented at the Maxey Flats, Kentucky disposal facility (high-care level denoted by 3). Additional information regarding the extent of long-term care activities assumed for each care level is provided in Appendix Q.

The Postoperational Period--IPO is a property of the disposal technology utilized and denotes the number of years between the cessation of active disposal of wastes and transfer of the site title to the site owner. It includes the closure period as well as any observation period implemented by the site operator, and it affects the time-delay factor. At a minimum, it would be equal to the two years required for the actions by the site operator to close the site prior to the transfer of the site title to the site owner. At a maximum, it may include four to possibly thirty years which may be required for site closure plus a number of years to verify that the site condition is suitable for the transfer of the site title to the site owner.

The Active Institutional Control Period--IIC indicates the number of years between the transfer of the site title to the site owner and the assumed loss of active institutional controls. This period also affects the time-delay factor.

3.2 Waste Form Behavior Indices

This section presents the manner in which waste form and packaging properties are handled in the impact calculational procedures. These properties are considered in the impact calculations in a manner similar to the disposal technology properties. They have been expressed through discrete indices, which are called the waste form behavior indices, that indicate a certain property of the waste form or a specific calculational procedure to be utilized in the impact calculations. The indices are summarized in Table G.13.

It has been common practice in the past to give little or no credit to waste form and packaging properties in the calculation of impacts (e.g., Refs. 24 and 25). Some credit was sometimes given to the comparative leachability of the solidification agent utilized and this effect was considered in ground-water migration impact calculations. However, a quantitative analysis of the mechanical, thermal resistance to chemical and biological attack, and other properties of the waste form and their effects on all the pathways considered has not been performed.

Table G.13 Waste Form Behavior Indices

Parameter and Symbol		Indices
Flammability	(I4)	0 = nonflammable 1 = low flammability (mixture of material with indices of 0 and 2) 2 = burns if heat supplied (does not support burning) 3 = flammable (supports burning)
Dispersibility	(I5)	0 = low 1 = low to moderate 2 = moderate 3 = severe
Leachability	(I6)	1 = unsolidified waste form 2 = solidification scenario A* 3 = solidification scenario B** 4 = solidification scenario C†
Chemical Content	(I7)	0 = no chelating agents or organic chemicals 1 = chelating agents or organic chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form 1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible 2 = moderately accessible 3 = accessible with difficulty

*50% urea-formaldehyde and 50% cement.
**50% cement and 50% synthetic polymer.
†100% synthetic polymer.

The primary reason for this past conservatism has been the lack of detailed data on the different types of wastes included in the impact analyses. All the LWR wastes or all the nonfuel cycle wastes, or both, were considered as one stream. A contributing reason for this conservatism has been the lack of data on the performance of the waste form over long periods of time. However, in this EIS, the waste has been separated into 36 individual waste streams and each stream is considered separately in the impact calculations. Consequently, wide variations in waste stream properties may be quantified based on the available qualitative and comparative data on the properties of each of these waste streams. Therefore, an attempt has been made in this EIS to quantify the waste form properties and their effects on the impact calculations.

As shown in Table G.13, six indices have been assigned to each waste stream for each waste spectrum considered: a flammability index, denoted by I4, a dispersibility index, denoted by I5, a leachability index, denoted by I6; a chemical content index, denoted by I7; a stability index, denoted by I8; and an accessibility index, denoted by I9. The waste streams considered in this work and the integer values for these six indices that have been assigned to each waste stream for the four waste spectra considered are given in Appendix D.

In addition to these six indices, two more indices for each waste stream are utilized in the impact calculations: the waste processing index--denoted by I10--is explained in Section 5; and the "disposal status index"--denoted by I11--is calculated during the impacts analyses and is explained in Section 3.4.

This section discusses the procedures through which these indices are incorporated into the analysis. Specific values assigned to the waste form properties, which are denoted by the waste form behavior indices, are discussed in Appendix D, Reference 1 and Reference 6. Below is a summary of the information presented in these references.

3.2.1 Flammability Index (I4)

This index ranks waste forms according to their flammability. Waste forms which will not burn even on prolonged exposure to open flame and moderately intense heat are assigned an index of 0. These consist of waste forms that experience no evidence of combustion or decomposition upon exposure to 1000°F for 10 minutes. Those waste forms that will sustain combustion are assigned an index of 3. These consist of waste forms such as liquids with flame points around 600°F. Between these extremes are two additional flammability categories. Waste forms which show evidence of combustion and/or decomposition upon exposure for 1000°F for 10 minutes but will not sustain burning when the heat source is removed are assigned an index of 2. Waste forms consisting of a mixture of materials with flammability indices 0 and 2 are assigned an index of 1 (Ref. 1).

The only scenario in which this index is utilized is the accident-fire scenario. Each waste stream is subjected to the accident scenarios separately. The accident-fire scenario is assumed to be possible only if (1) the waste stream being tested can support combustion (i.e., I4=3) or (2) the waste stream being tested is mixed during disposal with other waste streams containing combustible material. This latter case is possible if there is no waste segregation (i.e., IS=0).

In the accident-fire scenario, the total volume of waste subjected to the fire is assumed to be 50 m^3 (about 250 55-gallon drums or equivalent volume). This volume is estimated from an assumed volume of 200 m^3 of waste received daily at the disposal site (which corresponds to about 1,000,000 m^3 of waste over

20 years). Two of the disposal cells are assumed to be in operation simultaneously, and half of the waste in one disposal cell is subjected to the accident-fire scenario.

In another study, the fraction of waste released into the atmosphere as the result of an accidental fire has been estimated to be about 10^{-2} for combustible material, and about 10^{-5} for unsolidified resins (Ref. 8). It was estimated in this study that most of the radioactivity will remain in the ashes which remain localized. In a more recent report, it has been estimated that the fraction of combustible material released from an accidental fire involving LLW is about 10^{-3} (Ref. 26).

In this EIS, all unprocessed fuel cycle compactible trash, most of the institutional streams, industrial low-specific activity waste, and industrial tritium waste have been assumed to be combustible (see Appendix D), and have been assigned a flammability index of 3. Similarly unprocessed LWR resins and cartridge filters, some of the industrial trash streams, and wastes solidified in a synthetic polymer (solidification of scenario C) have been assigned a flammability index of 2. LWR-concentrated liquids and filter sludge have been assigned an index of 1. Noncombustible trash, process waste from fuel fabrication and UF_6 conversion plants, and high-specific activity industrial waste streams (see Appendix D) have been assigned an index of 0.

In this EIS, waste streams with indices of 3 and 0 have been assumed to release a fraction of 0.1 and 1.25 x 10^{-5} of their activity into the air, respectively, upon being subjected to the accident-fire scenario. The waste streams with flammability indices between these two extremes have been assigned a release fraction calculated from the geometric midpoints of these two values (each index value is 20 times the adjacent lower index value). The following table gives the assumed fraction of waste released for the respective indices.

I4	f_r
0	0.0000125
1	0.00025
2	0.005
3	0.1

In other words, f_r can be expressed by the value of $0.1 \times 20^{(I4-3)}$. These assumptions are believed to be very conservative, particularly for combustible streams. Noncombustible material (I4=0) is assumed to result in 1.25 x 10^{-5} fraction of the waste released into the atmosphere which is greater than the value quoted for unsolidified resins (Ref. 8).

3.2.2 Dispersibility Index (I5)

This index is a measure of the degree to which individual waste streams may be suspended as respirable particles should the waste form be exposed to wind or mechanical abrasion, such as from the actions of a potential inadvertent intruder, after a significant period (on the order of 100 years). It is recognized that there is considerable uncertainty in estimating the dispersibility of various waste forms over long time periods. However, the NRC staff believes that there is a need to consider the relative effect that improved waste forms have upon impacts to a potential inadvertent intruder. Therefore, two options exist for considering the relative effects of the dispersibility index in the calculations. In the waste form no-credit option, all waste forms are assumed to disperse into respirable fractions in a similar manner to ordinary dirt. This is the most conservative case and has been assumed by others (Refs. 24, 25). In the waste form credit option, assumptions and judgments are made regarding the comparative dispersibility of various waste forms. Then, estimates are made regarding the fraction of the waste released from the waste forms into respirable properties. This latter option is discussed below.

Waste forms which are assumed to have a low probability of becoming suspended into respirable particles are assigned an index of 0. Those waste forms which have a high potential of becoming suspended are assigned in index of 3. Waste forms which tend to crumble or fracture extensively and those forms that are subject to relatively rapid (within about 100 years) decomposition are assigned an index of 2. Waste forms consisting of a mixture of materials with dispersibility indices of 0 and 2 are assigned an index of 1.

The dispersibility of the waste form is dependent on the resistance of the waste form to chemical and biological attack (Refs. 1-6). Another property of the waste form that can be used to estimate the comparative values of this property is the compressive strengths of the waste forms (Ref. 1).

As an upper bound for this property, the most dispersible waste form (I5=3) has been assumed to be equivalent to soil, and no credit has been considered due to waste form. This value is believed to be conservative considering that the dispersed fraction of powdered PuO_2 packages in transportation accidents have been assumed to be 0.001 (Ref. 9). In comparison, wastes subjected to solidification scenario C (see Appendix D), which may be represented by the properties of waste solidified in a good synthetic polymer, are likely to resist biological and chemical attack and have significant compressive strengths (Ref. 6). These streams have been assumed to result in a low dispersible state, have been assigned an index of 0, and are assumed to have a fraction of 0.001 of the waste in a dispersible form. Other waste streams are assigned dispersibility indices in between these extremes (Ref. 1).

To summarize, for the waste form no-credit option, the fraction of the respirable dust loading in air that is contributed by each waste stream as a result of intruder activities or wind action is assumed to be equal to 1.0 for all waste forms. For the waste form credit option, this fraction is assumed to be equal to the following:

I5	f_r
3	1
2	.1
1	.01
0	.001

In other words, the factor f_r in the waste form credit option is given by the relationship $10^{(I5-3)}$. The dispersibility index is applied to the intruder-construction, intruder-agriculture, and exposed waste-wind transport scenarios.

3.2.3 Leachability Index (I6)

This index is a measure of a waste form's resistance to leaching and is primarily determined by the solidification procedures used. Unsolidified waste forms, which are assumed to be readily leached, are assigned an index of 1. Waste streams solidified according to solidification scenarios A, B, and C are assigned indices of 2, 3, and 4, respectively.

The solidification scenarios represent varying levels of performance that can be achieved through available solidification techniques. In this EIS, a level of performance designated by solidification scenario A has been simulated by assuming that half of the waste is solidified using urea-formaldehyde and the other half using cement; a level of performance designed by soldification scenario B has been simulated by assuming that half of the waste is solidifed using cement and the other half using synthetic organic polymers; and a level of performance designated by solidification scenario C has been simulated by assuming that all of the waste is solidified using synthetic organic polymers.

The primary purpose of this index is to assign values to the estimated leachability potential of solidified waste streams in comparison with unsolidified waste forms. Radionuclide-specific leaching fractions for unsolidified waste streams have been estimated based upon actual leaching data from two existing disposal facilities (see Section 3.5). The leachability index assigns values to a multiplier of these unsolidified waste stream leaching fractions. The product of the multiplier and the unsolidified waste leaching fractions gives, for each waste stream, the actual leaching fraction used in the radiological impact calculations. The multiplier is assigned a value of unity to unsolidified waste streams such as dewatered resins or trash and a value less than unity to solidified waste streams. The multiplier value assigned to solidified waste streams is dependent upon the particular solidification agent considered. Based on an analysis of the existing comparative leachability data (Ref. 1), the following values have been assigned to this multiplier:

I6	Multiplier
1	1
2	1/4
3	1/16
4	1/64

These values are applied primarily to the ground-water scenarios. Another scenario which may also be affected is the food (soil) uptake pathway of the intruder-agriculture scenario since the level of contamination in interstitial soil water available to vegetation may depend on the leachability of the waste. The use of this index as an option to help investigate the effect of waste form to reduce potential intruder impacts in these scenarios is presented in Sections 3.4 and 3.5. The value of the index, I6, however, may be further modified depending on properties of the waste and disposal technology (see below).

3.2.4 Chemical Content Index (I7)

This index denotes whether a waste stream may contain chelating agents or organic chemicals that may increase the mobility of radionuclides during and/or after leaching. An index value of 0 indicates the likelihood that these agents or chemicals are absent in the stream, whereas an index value of 1 indicates that the stream is likely to contain chelating agents or organic chemicals.

This index, in conjunction with the segregation option index IS (see Section 3.1.3) is used to modify the multiplier values assigned to the leachability indices for the ground-water and intruder-agriculture scenarios. The following table is used in determining the fraction leached from a particular waste form:

	Mult (I6,I7,IS)	
I6	IS=1 and I7=0	IS=0 or I7=1
1	1	1
2	1/4	1
3	1/16	1/4
4	1/64	1/16

This table should be interpreted as follows. For a waste stream with a given leachability index (I6), if the waste stream either contains chelating agents (I7=1) or is disposed mixed with other waste streams containing chelating agents (IS=0), then the higher leach fraction multiplier is used. If the waste stream does not contain chelating or chemical agents (I7=0) and it is not mixed with other wastes containing chelating or chemical agents (IS=1), then the lower leach fraction multiplier is used.

A similar procedure is applied to the retardation coefficients assigned to individual radionuclides. Retardation coefficients denote the potential of the disposal site soils to retard the radionuclides during ground-water migration. If there is no waste segregation at the disposal facility, then the retardation potential of the disposal site soils is assumed to be reduced as discussed in Section 3.5.

3.2.5 Stability Index (I8)

This index denotes whether the waste form is likely to reduce in volume after disposal due to compressibility, large internal void volume, and/or chemical and biological attack (no credit is taken for the waste containers). An index value of 0 indicates a likelihood of structural instability, whereas a value of 1 indicates a structurally stable waste form.

The stability indices have been assigned based on the physical descriptions of the waste provided in Reference 6. In general, this index has been assigned based on the void volume and/or compressibility of the waste and its biodegradability. For example, all trash waste streams are assumed to be unstable unless they are incinerated and/or solidified. Dewatered resins and filter sludges are also considered to be unstable. There is generally a 10 to 20% void volume within the disposal containers (liners). Organic resins are mostly composed of water, and water is present in the interstitial spaces between the resins. Finally, all waste forms expected to be packaged in trash or similar degradable void fillers, such as LWR noncompactible trash streams, are also assumed to be unstable. In this case, the waste form containing most of the activity can be considered to be stable. However, since this higher activity waste is packaged with compressible (degradable) material, the packaged waste stream will eventually degrade, produce voids within a disposal cell, and possibly lead to subsidence problems.

The use of this index depends on the stabilization index, IX. If IX is 3 (extensive stabilization measures are implemented), then the index I8 is ignored in the calculations. If IX is 1 (regular stabilization measures), then the segregation index IS also affects the calculational procedure. If IS=1 (segregation), then in ground water migration calculations a higher percolation estimate is adopted for wastes that are unstable (I8=0); if IS=0 (no segregation), then a higher percolation figure is adopted for all the streams (see Section 3.5).

Similarly, in the disposal cost calculations, if there is segregation, then any moderate or extensive stabilization measures (IX=2 or IX=3) are applied to only the disposal cells that contain unstable wastes; otherwise, the entire site undergoes these stabilization measures.

3.2.6 Accessibility Index (I9)

The index triggers the use of a correction factor for those unsolidified waste streams that have a comparatively higher metal content. The radionuclides contained in these waste streams are not as easily accessible to transfer agents such as wind and water as are the radionuclides contained in other waste streams.

Most of the waste streams contain surface-contaminated wastes and waste containing radioactivity in readily soluble form; these streams are assigned an accessibility index of 1. The waste streams that are almost exclusively activated metals with imbedded radioactivity not readily accessible to the elements are assigned an index of 3. Only the industrial high-activity waste stream has been assigned an index of 3. Several other streams containing a significant portion of metallic waste, which have both activated and surface crud contamination, have been assigned an accessibility index of 2. The value of this index does not change depending on the waste spectrum considered.

This index is applied to all the release/transport scenarios that involve wind or water transfer agents, and to all the direct radiation scenarios. In the calculations, the degree to which a waste form resists mobilization by external transfer agents is expressed through the waste form and package factor (f_w). One of the mathematical terms in the waste form and package factor is a fractional multiplier that expresses the effect of the accessibility index. This fractional multiplier is assumed to be given by the relationship 10 (Refs. 1-19); that is:

I9	Multiplier
1	1
2	.1
3	.01

These multipliers are assumed to be applicable to the above waste streams even after a long time. Most of the equipment and metals in these waste streams are manufactured from corrosion-resistant materials. A brief comparative discussion of the waste streams for which this index is different than unity is presented below.

The main purpose of the accessibility index is to evaluate the comparative isolation from transport agents of the radioactivity contained in certain unsolidified wastes. The function of this index is similar to that of the leachability index applied to solidified wastes. The reduction of accessibility of some radioactive materials is the result of the combined physical and chemical characteristics of the waste. No reduction is considered for wastes which contain radioactivity in forms which are readily soluble or displaced. Combustible trash and absorbed liquids are examples of these types of wastes.

At the other extreme are unsolidified waste streams such as activated metals where, in the absence of surface contamination, much less of radioactivity is initially accessible to transport agents. Industrial high-activity metals are assumed to be the only waste stream of this type which is virtually free of surface contamination. Many of these activated metals are high-alloy materials (alloys with a high nonferrous metallic component) and corrode very slowly in the disposal environment. For example, a corrosion rate of 0.002 mg/100 cm^2/day (7.3 x 10^{-6} g/cm^2/yr) has been quoted for high-alloy stainless steel (Ref. 1). Such corrosion produces finely divided but highly insoluble oxides.

Although insoluble, these oxides may be more accessible by virtue of being finely divided. The percentage of the total activity of such waste forms converted to the oxide from in a given time is highly dependent on the geometry of the waste (i.e., surface area to mass ratio). For example, consider a high-alloy rod 100 cm long and 1 cm in diameter and having a density of 7.8 g/cm^3

with a pipe having the same external dimensions and density but with a wall thickness of 0.1 cm. The surface area to mass ratios are 0.259 cm^2/g for the rod and 2.56 cm^2/g for the pipe. Assuming that the activation products are distributed uniformly through both pieces, the fraction of the activity lost from the pipe is nearly ten times that of the rod (1.87×10^{-5}/yr versus 1.89×10^{-6}/yr). The small magnitude of both numbers illustrates the inaccessibility of the radioactivity in both cases--especially in view of the insolubility of the corrosion products. In 1,000 years, only about 2 percent of the activity becomes available. Based on this, a conservative correction factor (multiplier) of 0.01 has been applied to the dispersibility of these wastes.

The remaining unsolidified wastes fall between these two extremes. Wastes in this group include the noncompactible trash streams and nonfuel reactor core components. The noncompactible trash streams include quantities of surface-contaminated failed equipment. Many pieces of equipment are internally, rather than externally, contaminated and are sealed to prevent release of any free liquids they may contain (e.g., pumps). A pump sealed with 1 cm thick carbon steel caps (corrosion rate of 0.03 cm/yr) (Ref. 8) would isolate the radioactivity for about 30 years. After this period the release of radioactivity is controlled by the activity and amount of liquid inside the piece, the nature of the internal contamination, and the ease with which the transport agents can get in and out of the equipment.

Nonfuel core components are another case. These components are generally highly activated stainless steel (or other alloys) pieces coated with crud deposits. The accessibility of the radioactivity of these wastes depends on the thickness of the crud layer and the relative activity of the crud and underlying metal. Crud mainly consists of oxides of iron and has been found to range in thickness from 0.0003 to 6 mil on fuel roads (Ref. 1). The strong decontamination agents necessary to remove such crud deposits from LWR primary cooling systems attests to the relative inaccessibility of the radioactivity they contain. Furthermore, the transporting medium must penetrate the crud layer to begin corroding the activated metal beneath. Because the fractions of activity of these components contained in the crud and the metal itself are not well-characterized, these wastes are considered to more closely resemble noncompactible trash rather than clean-surfaced high-activity metals.

A reduction factor for the direct radiation exposure components of the scenarios is also assumed to be applicable due to the high metal content of the streams with an accessibility index greater than 1. This reduction is due to the self-shielding afforded by the higher density metals and packaging practices. For example, the uncollided gamma flux from a half-space source at the surface is inversely proportional to the density of the material; this effect alone would result in a gamma flux attenuation by a factor of about 7 (Ref. 1). Furthermore, when these noncompactible metallic wastes, which usually have irregular shapes, are packaged, other materials such as trash or soil that usually have much lower activities are placed around them to fill the voids. For the high energy gamma rays found in LLW (Co-60, Cs-137, and Nb-94), it takes only about 2 inches of metal shielding to result in an attenuation of 10. In this EIS, in view of the above effects, a reduction factor of 10 has been applied to direct radiation exposure pathways for streams having an accessibility index greater than 1.

3.3 Waste Classification

As discussed in Section 2.2, potential long-term exposure scenarios from LLW disposal can be separated into two types: concentration scenarios and total-activity scenarios. The concentration scenarios include those involving direct human contact with the disposed waste, such as those involving exposures to a potential inadvertent intruder. In these scenarios, potential exposures are calculated considering only the radionuclide concentration in the waste streams assumed to be actually contacted by the intruder. The radionuclide concentrations and total activity in parts of the disposal facility not contacted by the potential inadvertent intruder do not enter into the calculations. On the other hand, exposures from the total activity scenarios are determined by considering the total radionuclide activity disposed at the facility. Examples of total activity scenarios include ground-water migration scenarios.

The fact that impacts from scenarios involving direct human intrusion into disposed waste are governed by the concentrations in the particular waste streams assumed to be contacted makes the intruder scenarios very useful for waste classification purposes. Assuming that a limit is placed on the exposures allowed to a potential human intruder, then the maximum allowable concentrations of radionuclides in waste streams to meet this exposure limit may be calculated.

Once concentration limits are determined, waste generators can relatively easily determine what class their waste is in by comparing the radionuclide concentrations in their wastes with the limiting concentrations determined through the intruder scenarios. Use of potential human intrusion as a means of classifying wastes for disposal has been also used by others (Refs. 24, 27).

By contrast, it is much more difficult to classify wastes through use of total activity scenarios such as ground-water migration. Comparatively speaking, impacts from ground-water migration are much more dependent on site-specific conditions than the intruder scenarios. In addition, since the potential impacts are a function of the total activity of waste disposed, it is difficult to set concentration limitations for individual radionuclides to meet a specific dose limitation criteria. It would be difficult, based upon ground-water migration considerations, to set concentration limits that can be used by a waste generator to determine the classification of this waste.

It is important to emphasize, however, that this does not mean that ground-water migration from a disposal facility is not an important consideration in LLW disposal. It does suggest that rather than establishing concentration limitations to be met by a waste generator to meet a particular ground-water exposure limitation criteria, it would probably be more useful to set an inventory limitation for a particular disposal facility (based upon site-specific information) for particular radionuclides of concern.

Then, if the waste generators were required to report the quantity of the radionuclides of concern which are contained in each shipment of waste that the waste generator ships to the particular disposal facility, the disposal facility operators could maintain a running inventory at the site of the radionuclides of concern. When the site inventory reaches the established limit for the facility, the disposal facility operator would no longer accept waste streams containing the particular radionuclides of concern. It is expected that such radionuclides of concern would include long-lived mobile isotopes such as ^{14}C, ^{99}Tc, and ^{129}I.

Potential inadvertent intruder exposures (and maximum radionuclide concentrations corresponding to a given dose conversion criteria) are a function of three general parameters: (1) the time after disposal that the intrusion occurs (the length of the active institutional control period), (2) waste form and packaging properties, and (3) disposal facility design and operating practices. Regulatory requirements can be placed upon these parameters and, depending upon the particular requirements placed upon these parameters, a classification system may be developed.

The effect of waste form and packaging properties and disposal facility design and operating practices on impacts from human intrusion is also extensively examined in Chapters 4 and 5 of this environmental impact statement. From this analysis two conclusions can be made:

- Barriers may be used to reduce the possibility of human intrusion. These barriers may include disposal at greater depths or emplacement of the waste using an engineered barrier designed to resist human intrusion (e.g., a caisson backfilled with concrete).

- If the waste is in a stable waste form that resists dispersion and if the stable waste is disposed in a disposal cell which is segregated from unstable waste forms, then potential intruder exposures would be reduced over those exposures expected if the stable wastes were disposed mixed with the unstable wastes.

Based upon establishment of a maximum time for active institutional controls and incorporating the above two conclusions, a waste classification system may be developed based on a maximum exposure limit to a potential inadvertent intruder.

The costs and relative effectiveness of various barriers against human intrusion have been analyzed in Reference 1 and Appendix F. In this work, three generic levels of intruder barriers are considered in detail, which correspond to three general levels of effectiveness against intrusion at three levels of overall costs: (1) no barrier; (2) layering; and (3) hot waste facility.

In the first case, the waste stream is assumed to be disposed in a "regular" manner without consideration of protecting a potential intruder. In the second case, the waste stream is assumed to be disposed at the bottom of the disposal cell, so that at least 5 meters of earth or other (lower activity) waste streams cover the layered waste. In the third case, the waste stream is assumed to be disposed in a hot waste facility, which for this EIS is taken to be a concrete-walled disposal trench. The waste is stacked into the trench, grouting is poured around the waste packages, and a concrete cover is then poured over the grouted waste mass, and finally 2 meters of soil is emplaced over the concrete cover. The effectiveness of the hot waste facility is somewhat speculative, but is included to indicate an upper level of protection against inadvertent intrusion that can be achieved through near-surface disposal.

In addition and based upon the analysis in Chapters 4 and 5, it is assumed that the operational practice of segregated disposal of stable waste streams from unstable waste streams results in reduced exposures to a potential intruder contacting the stable waste streams--at least for the first several hundred years following waste disposal. Segregated disposal of the stable waste streams greatly improves the stability of the disposal cells containing the stable wastes, resulting in significantly less water infiltration and subsidence problems for these disposal cells, and less decomposition of the disposal cell contents. Exposures to a potential inadvertent intruder contacting these disposal cells at the end of the institutional control period would be limited to those acquired during discovery of the waste. It is not credible, for example, to postulate that an intruder would construct a house in, or attempt to grow vegetables in, a disposal cell composed of such wastes as 55-gallon drums filled with concrete. This scenario, which can be considered to be a subset of the intruder-construction scenario, is termed the intruder-discovery scenario.

Finally, consideration needs to be given to the length of time that intruder barriers and segregation of stable wastes would serve to reduce or eliminate potential inadvertent intruder impacts. Based on the analysis in Chapters 4 and 5, a time period of 500 years after site closure is used as a limit of the effectiveness of layering and waste segregation. Following his time period, wastes disposed through layering and/or segregation are assumed to be as accessible to an intruder as waste disposed by regular means (i.e., nonsegregated disposal). A time period of 1000 years is assumed as a maximum length of time for a hot waste facility to be effective against intrusion.

These concepts are further expanded in the following two sections which present the calculational procedures for determining intruder exposures from the two basic intruder scenarios considered in this appendix. These include the intruder-construction scenario (and its subset, the intruder-discovery scenario) presented in Section 3.4.1 and the intruder-agriculture scenario presented in Section 3.4.2.

3.4 Waste Classification Scenarios

3.4.1 Intruder-Construction Scenario

This is one of the scenarios utilized to determine the classification status of the waste streams--the other scenario being the intruder-agriculture scenario. This section considers the values of the pathway barrier factors under alternative values of the waste form behavior indices and the disposal technology indices.

This scenario assumes that at some time after the end of operations at the disposal facility, institutional controls break down temporarily and an intruder inadvertently constructs a house on the disposal facility. In so doing, the intruder is assumed to contact the disposed wastes while performing typical excavation work such as installing utilities, putting in basements, and so forth. These typical activities should not be expected to involve significant depths--e.g., in most cases no more than approximately 3 m (about 10 ft). There is, however, a much less likely chance that some excavations could proceed at a lower depth. This could occur, for example, through construction of a sub-basement for a high-rise building.

To implement this scenario, the inadvertent intruder is assumed to dig a 3-meter deep foundation hole for the house. The surface area of the house is assumed to be 20 m by 10 m (200 m^2), which is a typical surface area for a reasonably large ranch-style house. The foundation hole is assumed to be 20 m by 10 m (200 m^2) at the bottom and 26 m by 16 m at the top (giving a 1:1 slope for the sides of the hole. The top 2 meters of the foundation is assumed to be cover material and the bottom 1 meter is assumed to be waste. This excavation would result in about 232 m^3 of waste being intruded into.

The equation describing human exposure for the intruder-construction scenario is as follows:

$$H = \sum_n (f_o f_d f_w f_s)_{air} C_w \, PDCF\text{-}2 + \sum_n (f_o f_d f_w f_s)_{DG} C_w \, PDCF\text{-}5 \qquad (G\text{-}8)$$

where H is the 50-year dose commitment in mrem, PDCF-2 and PDCF-5 are the radionuclide-specific pathway dose conversion factors discussed and presented in Section 2.4, and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n).

The first term of the equation calculates the impacts from the exposures due to suspension of contaminated dust into the air (inhalation of the contaminated dust and direct gamma exposure from the contaminated dust cloud) and the consumption of food grown nearby upon which the airborne contamination is assued to settle. The second term of the equation calculates the impacts from direct gamma exposure to the wastes during excavation. The values of the barrier factors are examined below in two subsections: regular waste disposal and disposal with barriers against intrusion.

Regular Waste Disposal

The time delay factor f_o is radionuclide-specific and is given by the following equation:

$$f_o = \exp [-\lambda T] \qquad (G\text{-}4)$$

where T is the time period between the end of active disposal operations and the initiation of the scenario (i.e., IPO plus IIC years), and λ is the decay constant of the radionuclide. This factor is the same for the air uptake pathways and the direct gamma pathway. The assumed time period is equivalent to the assumption that the intrusion scenario involves the last disposal cell constructed at the site and conservatively neglects the possibility that the intrusion scenario may involve one of the earlier disposal cells.

The site design and operation factor (f_d) denotes the dilution of the waste due to particular disposal practices regarding waste emplacement. Its value is assumed to be 0.5, 0.75, or 0.5, depending upon whether the waste disposal is random, is stacked, or is decontainerized, respectively. The effects of other classification tests on f_d are described in Section 3.3.2.

For the air uptake pathways, two options are available for determining the waste form and package factor, f_w. These options are incorporated to help investigate the potential for improved waste forms to reduce airborne intruder impacts. As discussed in Section 3.2.2, in waste-form credit option, f_w is given by the following formula:

$$f_w = 10^{(1-I9)} \times 10^{(I5-3)} \qquad \text{(G-9)}$$

In this equation, I5 is the dispersibility index (see Section 3.2.2) and I9 is the accessibility index (see Section 3.2.6).

However, for the waste form no-credit option, no-credit is given for the waste form to reduce the dispersibility of the waste stream. In this option, the multiplier $10^{(I5-3)}$ is set equal to 1.0 for all values of I5.

For the direct gamma exposure pathway, only the self-shielding inherent to the particular waste form affects the factor f_w. In this case, f_w is set equal to the following:

$$f_w = \text{Accessibility Multiplier} \times \text{Solidification Multiplier} \qquad \text{(G-10)}$$

The modification due to accessibility results from the substantial metal component of some waste streams. For example, a reduction in direct gamma exposure intensity by a factor of 10 can be achieved through shielding of about 2 inches of metal equivalent (Ref. 1). The accessibility multiplier is taken to be 1 if the index I9 is equal to 1 and it is 0.1 if the index I9 is equal to 2 or 3. The solidification multiplier is assumed to be 0.80 for those streams that are solidified using solidifcation scenario A or B procedures which contain a significant amount of cement; otherwise, this multiplier is assumed to be unity. Since the streams with an accessibiliy index different than 1 are never solidified, the minimum value of the factor f_w for the direct gamma exposure pathway is 0.1.

The site selection factor, f_s, is different for the air and direct gamma uptake pathways of the intruder-construction scenario. For the air uptake pathways, it is the product of the soil-to-air transfer factor T_{sa} (which depends on the environmental characteristics of the region in which the disposal facility is located) with the exposure duration factor (the fraction of a year that the construction takes place). For the direct gamma exposure pathway it is equal to just the exposure duration factor. These factors are discussed below.

In this EIS, the exposure duration is assumed to be 500 working hours. This is equivalent to a construction period of 3 months, which is believed to be reasonably conservative for typical housing construction. It is believed to be very conservative for activities involving use of heavy construction equipment. This gives a value of 0.057 for f_s for the direct gamma scenario. For the air pathways, this number is multiplied by a soil-to-air transfer factor given by the formula:

$$T_{sa} = [T_{sa}]_o \times (10/v) \times (s/30) \times (50/PE)^2 \qquad \text{(G-11)}$$

where $[T_{sa}]_o$ is equal to 2.53×10^{-10} (Ref. 1), v is the average wind speed at the site in m/sec, s is the silt content of the site soils in percent, and PE is the precipitation-evaporation index of the site vicinity indicative of the antecedent moisture conditions. For the reference disposal facility, these values were determined to be v = 3.61 m/sec, s = 50%, and PE = 91, yielding a value of 3.53×10^{-10} for T_{sa} (also see Appendix J). For an exposure duration factor of 0.057, this yields a site selection factor of 2.01×10^{-11} for the air uptake component of the construction scenario.

Disposal With Barriers Against Intrusion

The barrier factors f_d and f_s are affected if the waste is disposed using intruder barriers and/or if waste segregation is implemented at the disposal facility. For the air uptake pathways, (a) for layered disposal, the factor f_d is multiplied by a factor of 0.1 to indicate the likelihood of contact of the layered wastes by the intruder; and (b) for hot waste facility disposal, f_d is multiplied by a factor of 0.01.

For the direct gamma exposure pathway, (a) for layered disposal, f_d is multiplied by a factor of 1/1200 which denotes attenuation of the radiation through a layer equivalent to 1 meter of soil; and (b) for hot waste facility disposal, f_d is multiplied by a factor of $1/1200^2$ (Ref. 2) which indicates attenuation of the radiation through a layer equivalent to 2 meters of soil.

The site selection factor, f_s, is modified only if the waste form is stable and has been disposed in a segregated manner. In this case, which is termed the intruder-discovery scenario, the exposure duration factor is reduced from 500 hours to 6 hours for all the uptake pathways (Ref. 1).

3.4.2 Intruder-Agriculture Scenario

The intruder-agriculture scenario assumes that an intruder inadvertently lives on and consumes food grown on the disposal facility.

Farming is a surface activity and generally does not involve disturbing the soil for more than a few feet. As long as a cap of one or two meters is maintained over the waste, then it is very unlikely that agricultural activities would ever contact the waste. To implement the scenario at the end of the active institutional control period, however, a portion of the soil excavated during the intruder-construction activity (232 m^3 of waste and 680 m^3 of cover material) is assumed to be distributed around the house. After building the foundations of the house, about 312 m^3 of this soil would be backfilled outside and around the cellar walls, leaving a volume of about 600 m^3 of soil (of which about 150 m^3 is the original waste/soil mixture) involved in the agriculture scenario. The precise areal extent to which this soil is distributed is somewhat speculative. It is likely, however, that the soil will remain localized; moving even a few cubic yards of soil more than 10 meters usually requires a significant effort. It is assumed in this report that this areal extent is likely to be somewhere between 1000 m^2 and 2000 m^2. That is, the waste/soil mixture is assumed to lie within a radius of about 25 meters from the center of the house. The intruder is then assumed to live in this distributed waste/soil mixture and is also assumed to consume vegetables from a small garden located in the waste/soil mixture.

A possible alternative to this scenario is that the waste cover is stripped away by the intruder, and that the intruder lives on and grows and consumes food grown directly in the waste. This does not appear to be as reasonable as the above scenario. At current commercial rates, it costs about $1.07 to move one cubic yard of dirt from one place to an adjacent place with heavy equipment (Ref. 28). This implies that to clear 2 meters of cover from 2 acres, the intruder would have to either invest a sum of about $22,500 or perform labor equivalent to this sum. This is not a reasonable assumption since no reasonable person is likely to strip and clear away surface soil with the hope of finding better soil underneath to grow food. A noncommercial enterprise is therefore assumed for the intruder-agriculture scenario. It appears to be unreasonable to expect that a commercial operator, who would require a substantial investment for a commercial agricultural operation and therefore a clear title to the land, can be an inadvertent intruder.

The inadvertent intruder is assumed to live in the house built on the site, work at a regular job during the day, and spend some of his extra time working in a garden growing vegetables for his own use. His time during a year is assumed to be allocated between various activities as follows:

Activity	Hours/Year
At Home	4380
At Work	2000
Traveling To and From Work	250
Vacation	330
Gardening	100
Outdoors	1700
Total:	8760

In the intruder-agriculture scenario, the inadvertent intruder could be exposed principally by five pathways: (1) inhalation of contaminated dust suspended due to tilling activities as well as natural suspension, (2) direct gamma exposure from standing in the contaminated cloud, (3) consumption of food (leafy vegetables) dusted by fallout from the contaminated cloud, (4) consumption of food grown in the contaminated soil, and (5) direct gamma exposure from the disposed waste volume. For calculational convenience, the first three uptake pathways have been grouped together and denoted as the air uptake pathway. The potential exposures from these pathways are calculated in three groups: air uptake, food (soil) uptake, and direct gamma (volume) exposures. These are then added to arrive at the total potential exposures from this scenario.

In this EIS, the potential exposures from the intruder-agriculture scenario are calculated using the following equation:

$$H = \sum_n (f_o f_d f_w f_s)_{air}\, C_w\, \text{PDCF-3} + \sum_n (f_o f_d f_w f_s)_{food}\, C_w\, \text{PDCF-4} + \sum_n (f_o f_d f_w f_s)_{DG}\, C_w\, \text{PDCF-5} \qquad \text{(G-12)}$$

where H is the annual dose in mrem per year during the 50th year of exposure, PDCF-3, PDCF-4, and PDCF-5 are the radionuclide-specific dose conversion factors presented in Section 2.4, and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n). The values of the barrier factors are presented below.

The time delay factor, f_o, for this scenario is identical with the construction scenario, and is given by equation (G-4). The site design and operation factor f_d is also determined in the same manner as the construction scenario. In addition, the dilution resulting from mixing the excavated waste (232 m^3) with the excavated cover soil (680 m^3), which is a factor of about 0.25, is also included in the design and operation factor.

The waste form and package factors for the air uptake and direct gamma exposure pathways composing this scenario are identical to those for the air uptake and direct gamma pathways composing the intruder-construction scenario.

For the food (soil) uptake pathway, two options are available to calculate f_w, depending upon whether credit is given for the waste form to reduce leaching of radionuclides from disposed waste and subsequent uptake by plant roots. These options are included to help investigate the potential for improved waste forms to reduce potential intruder impacts. For the waste form credit option, the following formula is utilized to calculate f_w for the food (soil) uptake pathway (also see equation G-16):

$$f_w = M_o \times t_c \times \text{Mult}(I6,I7,IS) \times 10^{1-I9} \qquad \text{(G-13)}$$

However, in the waste form no-credit option, the factor Mult(I6,I7,IS) is set equal to 1.0.

In equation G-13, M_o is the radionuclide-specific leach fraction of unsolidified waste forms (see Section 3.5). The contact time fraction t_c is the fraction of time in one year that the waste is in contact with irrigation or rainwater, while I9 is the accessibility index (see Section 3.2.6). Mult(I6,I7,IS) is the reduction due to solidification and the presence or absence of chelating chemicals (see Section 3.2.4) and is a function of leachability index (I6), the chemical content index (I7), and whether the waste streams containing chelating or chemical agents have been segregated from other waste streams (IS).

It appears to be reasonable to assume that only the fraction of radionuclides transferred from the waste to the interstitial water will be accessible to the roots. Inclusion of contact time in the above equation is consistent with this approach. The contact time fraction is conservatively assumed to equal unity in this EIS; however, this fraction may actually be a very low value in view of the soils likely to be found at most disposal locations. These locations are likely to be at topographic highs whereas the most attractive agricultural soils are found in or adjacent to flood plains.

The site selection factor f_s for the air uptake pathway is similar to the intruder-construction air uptake pathway. However, the soil-to-air transfer factor must be averaged to account for natural resuspension of the soils during part of a year. This estimate is calculated by assuming that (1) the construction scenario T_{sa} value of 3.53×10^{-10} (see Section 3.3.1) is applicable during gardening (100 hours); (2) during the time spent outdoors (1700 hours), typical natural outdoor ambient air particulate concentrations of 100 ug/m^3 are assumed to prevail (Ref. 27); and (3) during the time spent indoors (4380 hours), typical ambient indoor concentrations of 50 ug/m^3 have been assumed (Ref. 27). Utilizing a mass loading of 565 ug/m^3 for the time spent while gardening (Ref. 1), and averaging these values results in a site-selection factor value of 3.18×10^{-11}. This may be compared with the value of f_s (2.01×10^{-11}) calculated for the intruder-construction scenario.

For the food (soil) uptake pathway, f_s is taken to be the fraction of food grown onsite that is consumed by the individual. This value is assumed to be 0.5. For the direct gamma exposure pathway, f_s is equal to the exposure duration fraction multiplied by a correction factor to account for the limited areal extent of the direct gamma source that the intruder is exposed to. Moreover, the fraction of the time the intruder spends in relation to the source must be considered.

During a year, the intruder is assumed to spend 1800 hours outdoors exposed to unattenuated radiation (100 hours tilling and 1700 hours around the house). During the 4380 hours he spends indoors, he is exposed to attenuated radiation. The correction factor due to the areal extent of the source may be estimated utilizing Figure G.5. This figure shows that the intruder may be assumed to be exposed to a full disk source while outside, and an annular source while inside the house. While he is inside the house, the center of the disk

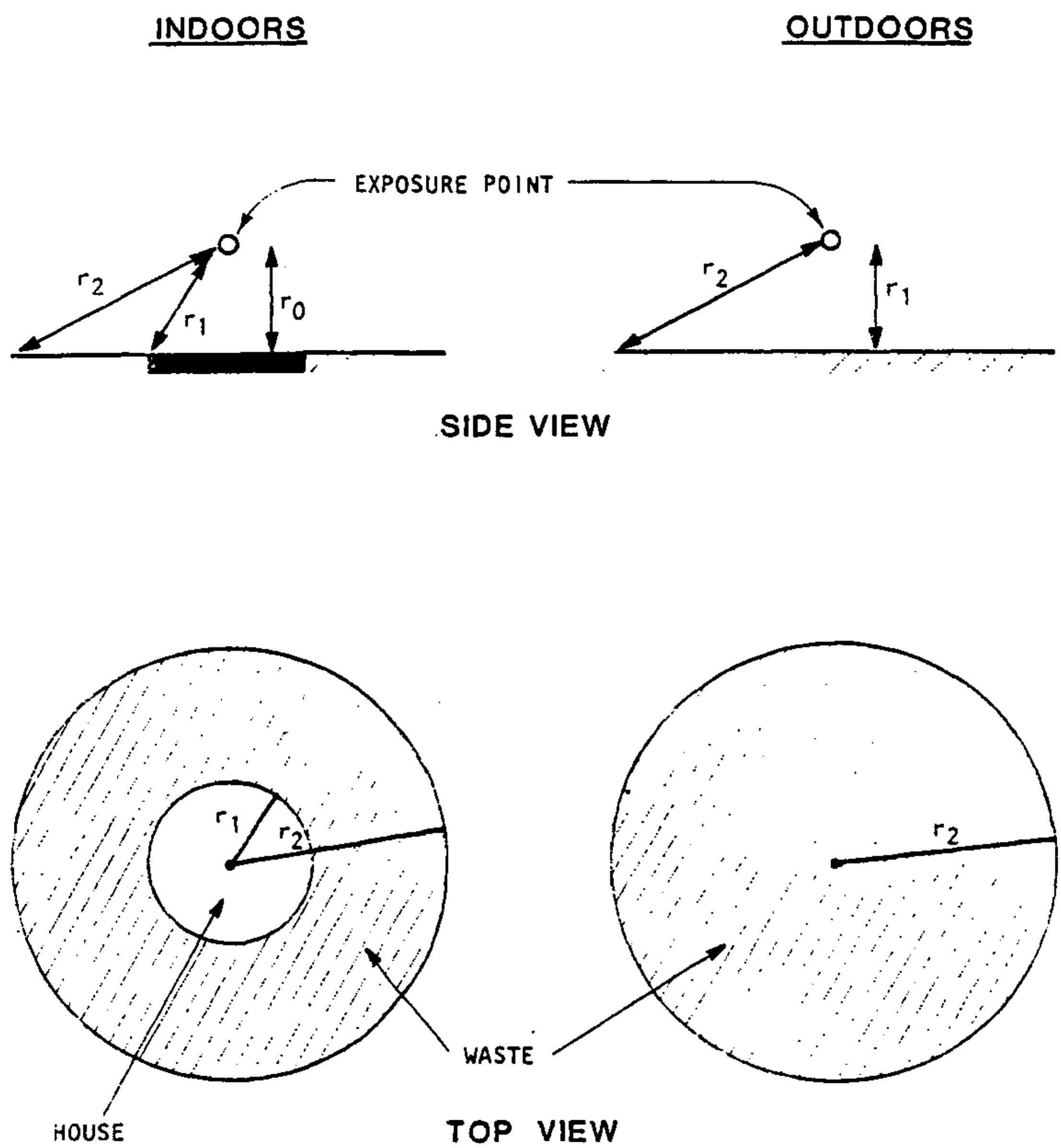


Figure G.5 Direct Gamma Exposure Geometry represents the shielding provided by the foundation slab. The contribution to the direct gamma exposure from this center portion may be neglected in comparison with the exposure from the outside of the house. If the foundation slab is a one-foot thick concrete layer, the radiation would be attenuated to about 0.03 of its unshielded value for Cs-137 gamma rays (Ref. 1). The correction factor for the areal extent of the annular source may be represented by the following equation:

$$c = [E_1(\mu r_1) - E_1(\mu r_2)] \,/\, E_1(\mu r_o) \qquad \text{(G-14)}$$

where c is the dimensionless correction factor, $E_1(x)$ is the first order exponential integral, μ is the linear attenuation coefficient of air in units of m^{-1} (it is taken to be 0.0097 m^{-1}) and the r's are the distances indicated in Figure G.5 in meters (Ref. 1).

For a full disk source (for the time spent outdoors), the radius r_1 in equation G-14 is replaced by r_o. In order to evaluate the correction factor, the distances must be assumed. The following table gives the value of the exponential integral for some representative distances:

Distance	μr	$E_1(\mu r)$
1 m	0.0097	4.068
8 m	0.0776	2.055
20 m	0.1940	1.335
25 m	0.2425	1.068

For r_o and r_1, it is reasonable to assume 1 m and 8 m, respectively; 1 m represents the height of the exposed person, and 8 m represents the approximate radius of a 200 m^2 house floor. The value assigned to r_2, however, depends on the areal extent to which the waste/soil mixture (600 m^3) has been spread. This mixture will likely be spread unevenly within about a half acre around the house excavation, and the areal extent is likely to be between 1000 m^2 and 2000 m^2. A radius of 20 m represents an area of about 1050 m^2 over which the waste is spread, while a radius of 25 m represents an area of about 1750 m^2. A radius of 25 m is utilized in this EIS.

These assumptions yield a correction factor for the time spent outdoors of about 0.74, and a correction factor for the time spent indoors of about 0.24. Utilizing values of 1800 hours outdoors and 4380 hours indoors yields a site selection factor of about 0.27, which is the value utilized in this EIS.

3.5 Ground-Water Scenarios

These scenarios calculate the impacts resulting from ground-water migration of radionuclides from the disposed wastes to four potential biota access locations downstream in the direction of the ground-water flow: (1) a well located at the boundary of the disposal area; (2) a well located at the site boundary;

(3) a well located between the disposal facility and the surface hydrologic boundary; and (4) a stream located at the surface hydrologic boundary. Different pathway dose conversion factors are used depending on whether the access location is a well or a stream (see Section 2). An idealized map showing the geometric relationships between the disposal facility and the biota access locations are shown in Figure G.6.

As shown in this figure, the main streamline passing underneath the disposal facility has been straightened out (the longitudinal coordinates are measured along this streamline), and the disposal area (excluding the 30 m wide buffer zone), which is assumed to cover an area of 450 m x 800 m, has been divided into 10 sectors.

The following equation is used to calculate human exposures which may result from the well access ground-water scenarios:

$$H = \sum_{i} \sum_{n} (f_o f_{di} f_{wi} f_{si})\, C_w \text{ PDCF-6} \qquad \text{(G-15)}$$

where H is the annual dose rate in mrem per year during the 50th year of exposure, PDCF-6 is the radionuclide-specific pathway dose conversion factor presented in Section 2.4, and C_w is the radionuclide concentration of the waste stream considered. The impacts are summed over all the waste streams (i), and over all the radionuclides (n). For a surface water access location the dose conversion factor PDCF-7 is substituted instead of PDCF-6. The values of the barrier factors are presented below.

The time delay factor f_o is assumed to be 1. This merely means that the ground-water scenario is assumed to be initiated at the close of the twenty-year operational period. The site design and opration factor f_d, is utilized to incorporate modifications resulting from two of the site design options: use of a hot waste facility, and grouting (the effect of the cover is incorporated into the waste form and package factor f_w for calculational convenience--see below). If the waste is grouted, then f_d is taken to be 0.1. If the waste is placed in a concrete-walled trench or a hot waste facility, f_d is further reduced by a factor of 0.1 (Ref. 1).

3.5.1 Source Term

The source term is represented by the waste form and package factor, f_{wi}, which has units of m³/year, and denotes the annual volume of contaminated liquid that leaves the disposal cells. This factor is given by the formula:

$$f_{wi} = f_i \times V_w \times f_c \qquad \text{(G-16)}$$

where f_i is the fraction of the disposed waste that is in the (i)th waste stream; V_w is the annual volume of water that percolates through the trench cap and contacts the disposal volume containing the waste; and f_c is the waste radionuclide concentration fraction transferred to the leachate.

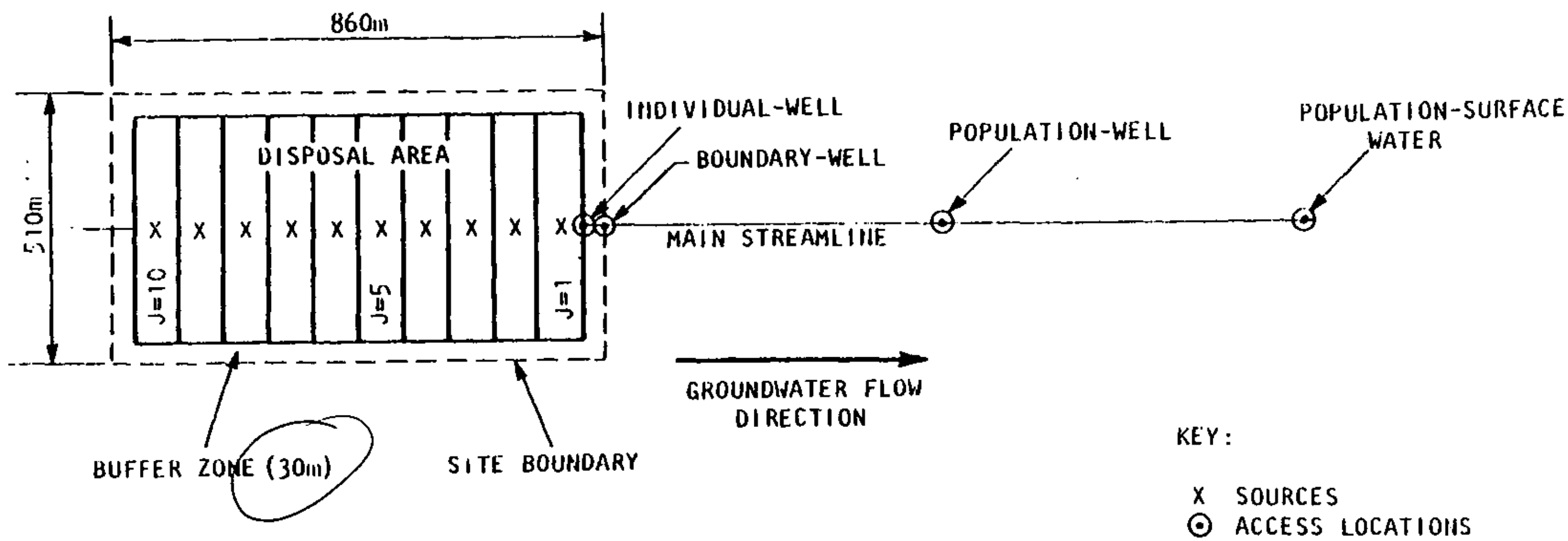


Figure G.6 Geometric Relationships of Disposal Area and Discharge Locations

The first factor f_i is self-evident; it is the ratio of the volume of the waste stream being considered to the entire volume of waste disposed at the facility. The variable (V_w) is simply the percolation (p) multiplied by the appropriate surface area. There are several different techniques for calculating the parameter (p) (also called PERC in several references).

One of these methods, usually called the water-balance technique, yields a percolation component of about 180 mm of water per year for the reference disposal facility. This value is applicable to those cases where no special effort has been made to emplace a moisture barrier over the waste and to those cases where the barrier integrity cannot be assumed due to instability of the disposed waste (Ref. 1).

For the cases where low permeability trench covers are employed and where the trench cover integrity can be assumed, the percolation component may be determined by the Darcy velocity of the least permeable stratum between the waste and the atmosphere. The Darcy velocity of a material, with hydraulic conductivity (K) in units of m/yr and unit hydraulic gradient (the most conservative assumption), has units of m^3/m^2-yr. This number, however, is modified by the fraction of each year during which there is at least 0.01 inch of precipitation. Therefore, in this latter case, (p) will be calculated from the relationship: p = K (w/365), where (K) is the hydraulic conductivity of the least permeable layer covering the waste, and (w) is the mean annual number of days with 0.01 inch or more of rainfall. Assuming that a permeability of 3 x 10^{-7} cm/sec (about 0.3 ft/yr) is applicable for the least permeable stratum of the low permeability trench cover, and assuming (for the reference disposal facility) that w is equal to 115, yields an estimated percolation component of 30 mm. This permeability can be readily achieved through emplacement and compaction of a clay layer (materials with permeabilities in the range 10^{-7} to 10^{-9} cm/sec are commonly available) (Ref. 1). However, after the active institutional control period, it is likely that, as a result of intrusion by humans and/or by plant roots and/or burrowing animals, this low percolation rate may increase. Therefore, a time-dependent source term option has been incorporated into the calculations as discussed below in Section 3.6.3.

For the reference disposal facility, V_w is therefore assumed to be given by either V1 = 0.180 S_f, or V2 = 0.03 S_f where S_f denotes the surface area involved, in m^2 (Ref. 1). However, the specific value utilized for this parameter is also determined by other factors. These include the cover index (IC), the stabilization index (IX), the waste form stability index (I8), and the segregation index (IS). The following table is utilized to arrive at the value of V_w for a given waste stream:

Cover	Cell Stabilization	Waste Stability	Infiltrating Volume: No Segregation	Infiltrating Volume: Segregation
Regular	Regular	Stable	2xV1	V1
	Regular	Unstable	2xV1	2xV1
	Moderate	Stable	1.5xV1	V1
	Moderate	Unstable	1.5xV1	1.5xV1
	Extensive	Stable	V1	V1
	Extensive	Unstable	V1	V1
Thick	Regular	Stable	2xV1	V2
	Regular	Unstable	2xV1	2xV1
	Moderate	Stable	2xV2	V2
	Moderate	Unstable	2xV2	2V2
	Extensive	Stable	V2	V2
	Extensive	Unstable	V2	V2

One more waste form behavior index affects the determination of the infiltrating volume, and that is the "disposal status" index I11. If the waste is disposed of in concrete-walled trenches or a hot waste facility (I11 = 3), the above table is ignored, and the infiltrating water volume is taken to be V2/4 multiplied by the surface area fraction of the walled trench or hot waste facility.

For the time-dependent source analysis option, an increase in the infiltration rate is assumed after the active institutional control period as follows. Only the infiltrating volumes that are less than V1 are affected. For 10 percent of the disposal area which is assumed to be disturbed by intruder activities (about 8 acres) an infiltrating volume of V1 is assumed, and for the rest of the area twice the previous value (i.e., either 4xV2 or 2xV2) is assumed. For the hot waste facility, the infiltrating volume is assumed to become V2.

The factor f_c represents the fraction of the radionuclides that are transferred from the waste to the leachate. It may be calculated using the following formula:

$$f_c = M_o \times t_c \times \mathrm{Mult}(I6,I7,IS) \times 10^{(1-I9)} \qquad \text{(G-17)}$$

where M_o is equal to the radionuclide-specific unsolidified waste leach fraction at continuous full saturation; t_c is the fraction of a year that the infiltrating volume of water is in contact with the waste; Mult(I6,I7,IS) is the reduction in leachate concentration considering solidification methods and disposal facility operation practices (see Section 3.2.4); and $10^{(1-I9)}$ is the accessibility factor (see Section 3.2.6). These factors are discussed below.

The factor M_o can be estimated by many theoretical methods; however, these theoretical calculations are not consistent with experimental data (Ref. 1). In this work, the average upper bounds of the leach fraction for unsolidified waste are estimated assuming that the leachate/waste conditions at the Maxey Flats, Kentucky disposal facility and the West Valley, New York disposal facility trenches (both of which can be assumed to be at continuous full saturation) may be used to approximate this bounding fraction. The above two disposal facilities, because of the presence of organic chemicals and chelating agents and because they can be assumed to be at continuous full saturation, may be assumed to represent extreme leachability conditions. Some researchers in the field believe that these types of estimates represent the best that can be achieved with the available experimental data (Refs. 1, 27).

To estimate these ratios, the measured leachate concentrations and the estimated trench inventories from several trenches for each radionuclide are utilized. This estimate takes into consideration the fraction of the leached radioactivity that may be reversibly adsorbed by the interstitial trench soils. These ratios are presented in Table G.14. Detailed calculations can be found in Reference 1.

The use of the factor M_o, however, necessitates a correction factor to take into account the transient and partially saturated conditions expected in the reference disposal facility. This correction factor is expressed through t_c. This fraction depends on the contact time between the waste and infiltrating water. Assuming that leaching at partial saturation is proportional to the moisture content, the fraction (t_c) may be expressed as the fraction of a year that the percolation component calculated above takes to pass through a given horizontal plane. That is, $t_c = p/(nv)$, where p is the precipitation (in m/yr) that infiltrates and comes into contact with the waste, n is the waste cell effective porosity, and v is the speed of the percolating water (in m/yr). The waste cell effective porosity can conservatively be assumed to be about 25% (partially compacted soils are likely to have higher porosities). The value of v depends on the interstitial soils; a very conservatively low value of 1 ft/day (corresponding to a permeability of about 1×10^{-4} cm/sec, an effective porosity of 0.25, and a hydraulic gradient of unity) will be assumed in this report for the reference disposal facility. These calculations yield the values 0.00647 and 0.00108 as the contact time factor for the above percolation cases of 0.18 m/year and 0.03 m/year, respectively (Ref. 1).

These values may be modified for soils with different permeabilities by multiplying by the ratios of the respective permeabilities; the contact time factor would increase for soils with low permeabilities, and would decrease for soils with high permeabilities by as much as a factor of 10. It should be noted that an increase or decrease in the volume of percolating water also affects the contact time.

The last two factors in equation (G-17) are the multipliers due to waste solidification and facility operating practices, and due to the relative inaccessibility of activated radioactivity in metal waste streams. The

Table G.14 Radionuclide Partition Ratios* Between Leachate and Waste

Basic Nuclide	Calculated Ratio	Other Nuclides	Assumed Ratio
H-3	1.15	Tc-99	0.115
		I-129	0.115
C-14**	5.76×10^{-3}		
Co-60	1.48×10^{-2}	Fe-55	1.48×10^{-2}
		Ni-59	1.48×10^{-2}
		Ni-63	1.48×10^{-2}
		Nb-94	1.11×10^{-2}
Sr-90	9.86×10^{-3}		
Cs-137	1.62×10^{-4}	Cs-135	1.62×10^{-4}
U-238**	1.25×10^{-4}	U-235	1.25×10^{-4}
Pu-239†	4.67×10^{-4}	Pu-238	4.67×10^{-4}
		Pu-241	4.67×10^{-4}
		Pu-242	4.67×10^{-4}
		Np-237	4.67×10^{-4}
		Cm-243	4.67×10^{-4}
		Cm-244	4.67×10^{-4}
Am-241	4.11×10^{-3}	Am-243	4.11×10^{-3}

*Ratio of the leachate concentration (in Ci/m^3) to the waste concentration in (Ci/m^3). Assumed ratios are estimated based on chemical similarities between the basic nuclide and the nuclide of concern.

**Calculated using West Valley leachate concentrations and Maxey Flats inventories.

†The calculated ratio includes Pu-238.

multiplier due to waste solidification and facility operating practices has been discussed in Section 3.2.3, and the table detailing the Mult(I6,I7,IS) factor in Section 3.2.5 is applied to this scenario. The multiplier for activated metal waste forms has been discussed in Section 3.2.6.

3.5.2 Migration Reduction Factor

The waste form and package factor, as expressed above, yields the total (in m^3/yr) source term that can be expected from a given waste stream. This source term must be related to the radionuclide concentrations at the ground-water biota access locations. This relation is expressed through the site selection factor (f_s) in units of yr/m^3. This factor, which has also been called the "confinement factor" or "reduction factor" (Ref. 3) is the ground-water migration analog of the (X/Q) term in meteorological diffusion calculations (Ref. 1).

Dozens of models, both analytical and numerical, have been developed to forecast the probable extent of radionuclide migration (sometimes called mass transport) and the associated environmental impact. A review of some of the available simulation techniques are presented in References 29 and 30. An analytical model is used in this EIS due to the generic nature of the analysis (Ref. 1).

The measurable hydrogeological parameters that should be included in an accurate simulation of mass transport are: the geometry of the problem (e.g., the travel distance and time to an access location), the decay constant of the radionuclides, the hydraulic velocities of the fluid (e.g., v), the dispersion characteristics of the medium, and the retardation coefficients of the radionuclide-medium interaction. The space- and time-averaging of the above parameters, if necessary, may be accomplished in a straightforward manner (Ref. 3). As discussed in Section 2.4, it can be shown that the time dependent site selection factor is given by (Ref. 3):

$$f_{si} = [r_g/Q] \sum_j r_{tij} \qquad \text{(G-18)}$$

where (Q) is the dilution factor in units of volume/time; the factor r_g is the time independent reduction factor due to the geometry of the problem (i.e., the spatial relationship of the disposal cells and the access location); j denotes the longitudinal sectors of the disposal facility shown in Figure G.6; and r_{tij} is the reduction factor due to migration and radioactive decay which depends on both space and time, including the duration of the source term (T_i).

The geometric reduction factor r_g is assumed to be independent of the characteristics of the waste streams. It is also independent of the longitudinal relationship of the disposal facility with the access location. A more detailed consideration of this factor is presented in Reference 1. In this EIS, it is conservatively assumed that the geometric reduction factor is unity.

The dilution factor Q is independent of the characteristics of the waste stream and the geometrical relationship of the disposal facility with respect to the access locations. The factor Q may be the pumping rate of a well or the flow rate of a stream. In this EIS, the dilution rates assumed are 7700 m^3/year (3.84 gallons per minute) for the intruder well and boundary well scenarios which represents the needs of a single person living in a rural area; 200,000 m^3/year (about 100 gpm) for the population well scenario; and 4.5×10^6 m^3/year (about 5 cubic feet per second) for the surface stream scenario (Ref. 1). Small farming communities that utilize ground water for their needs usually have wells that range from 100 gpm to 1000 gpm depending on the population (Ref. 1). A stream flow rate of about 5 cfs is selected since a stream with flow rate below this value is very unlikely to be used for human consumption. For example, Rock Lick Creek nearby the Maxey Flats, Kentucky disposal facility has an annual average flow rate of about 7 cfs, but it is not used for human consumption; it is used only for livestock (Ref. 1).

There exists a lower bound, however, for the value of the dilution factor Q, and it is given by the total volume of water infiltrating through the disposal area. This volume is calculated during the source term calculation presented in the previous section. Therefore, the value of Q is modified upward if the total volume of water infiltrating into the disposal area is greater than the above assumed values.

The migration reduction factor r_{tij} depends on the time that the exposure is assumed to occur, the duration of ground water travel between the j^{th} longitudinal section of the disposal facility and the access location, the retardation capability of the soils (radionuclide dependent), the duration of the assumed source term, and the waste stream characteristics. The longitudinal extent of the disposal facility is considered by dividing it into 10 sectors and summing the contributions (assumed to be equal) from each sector to obtain the concentrations at the discharge location. In this EIS the following formula is used for the migration reduction factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(J x T_i)] \times [F_j(t) - F_j(t-T_i)] \qquad \text{(G-19)}$$

where λ is the decay constant of the nuclide, t is the time at which the migration reduction factor is applicable; J is the total number of longitudinal sectors the disposal site has been divided into, which is 10 in this EIS (see Figure G.6); T_i is the source duration factor for the i^{th} waste stream; and j denotes the sector considered. The function $F_j(t)$ is given by the following formula (Ref. 1):

$$F_j(t) = 0.5 \times U(t) \times [\text{erfc}(X_-) + \exp(P_j)\ \text{erfc}(X_+)], \text{ where} \qquad \text{(G-20)}$$

$$X_{\pm} = \frac{\sqrt{P_j}\ [1 - t/(Rt_{wj})]}{2 \quad \sqrt{t/(Rt_{wj})}}$$

In this equation, U(t) is the unit impulse function that is zero for a negative argument and is equal to unity otherwise; t_{wj} is the water travel time between the disposal sector being considered and the access location; P_j is the Peclet number for the distance between the disposal sector and the access location; and erfc(x) is the complement of the error function and is given by the formula (Ref. 31):

$$\mathrm{erfc}(x) = 1 - \int_0^x (2/\sqrt{\pi}) \exp(-t^2)\, dt \qquad \text{(G-21)}$$

The retardation factors (R) that are utilized in the above equations depend on the radionuclide considered as well as the geochemistry of the soils and the transporting ground water. They are indicative of the reversible ion exchange capability of the soils and represent the ratio of the radionuclide velocities in the soil to the ground-water velocities. The cation exchange capacity of the soils is an important parameter which can be used to estimate the retardation coefficients of the soils from published data. Five sets of retardation coefficients are utilized in this EIS (Refs. 32, 33). These coefficients are presented in Table G.15.

The first set is representative of coefficients for sandy soils with low to moderate cation exchange capacities, and is assumed to represent the lower bound of retardation coefficients used in this generic analysis. The fourth set is representative of coefficients for clayey soils with moderate to high cation exchange capacities. In between these two sets, two other sets have been postulated and have been calculated utilizing the geometric midpoints of sets 1 and 4. The third set of coefficients have been assumed to be applicable to the reference disposal facility. A fifth set of coefficients have been also calculated for use in special cases.

The source duration factor T_i for the i^{th} waste stream is determined by dividing the total activity in the stream with the annual radionuclide release fraction which is given by the factor f_{wi} multiplied by the concentration. This calculation considers radionuclide decay but conservatively neglects the depletion of the radionuclide inventory at the site by previous releases. In other words, rather than having an inventory and a source term lasting for an infinite period of time with a pseudo-exponential decay (with the decay constant determined by the annual releases), all the radioactivity is released within a finite period with the annual source term determined with no depletion due to previous releases. This conservatism, which is equivalent to the assumption that waste/leachate transfer factor increases with time, is implemented for calculational convenience.

The ground-water travel times t_{wj} and Peclet numbers P_j depend on the distance between the disposal facility sector being considered and the access location. The travel time and Peclet number between the first sector and the access location are termed tw_1 and P_1, respectively, and appropriate multiples of the incremental ground-water travel time and Peclet numbers between two adjacent sectors are added to tw_1 and P_1. For the reference disposal facility, the

Table G.15 Sets of Retardation Coefficients* Used in Impacts Analysis

	Assumed Retardation Coefficients					
Nuclide	Set 1	Set 2	Set 3	Set 4	Set 5	BNWL**
H-3	1	1	1	1	1	1
C-14	10	10	10	10	10	10
Fe-55	630	1290	2640	5400	11050	3333
Ni-59†	420	860	1750	3600	7350	333
Co-60	420	860	1750	3600	7350	333
Sr-90	9	18	36	73	146	100
Nb-94	1000	2150	4640	10000	21500	10000
Tc-99	2	3	4	5	6	1
I-129	2	3	4	5	6	1
Cs-137†	85	173	350	720	1460	1000
U-235†	840	1720	3520	7200	14730	14286
Np-237	300	600	1200	2500	5000	100
Pu-238†	840	1720	3520	7200	14730	10000
Cm-243†	300	600	1200	2500	5000	3333
Am-241†	300	600	1200	2500	5000	10000

*Sets 1 and 4 are values obtained from Reference 32, except for the radionuclides Nb-94 and U-235. These values are based on comparative retardations given by the BNWL column (Ref. 33). Sets 2 and 3 are obtained as geometric midpoints of Sets 1 and 4, and Set 5 is similarly calculated, i.e.,:

Set 2 = Set 1 x Cube Root of (Set 4/Set 1),
Set 3 = Set 2 x Cube Root of (Set 4/Set 1),
Set 5 = Set 4 x Cube Root of (Set 4/Set 1).

**These values are given in Reference 30 for desert soils with a moderate cation exchange capacity of about 5 meq/100 g. They have been used as a guide to fill in missing values.

†Coefficients for other isotopes of these elements are assumed to be the same.

ground-water travel time between two adjacent sectors (a distance of 80 meters) is assumed to be 64 years (corresponding to a ground-water speed of 1.25 m/year). It is also assumed for the reference disposal facility that ground water takes 10 years to traverse the unsaturated zone. The Peclet number, P_i, is basically the distance to the access location divided by the longitudinal dispersivity of the medium. A value of 1600 is added for two adjacent sectors to the Peclet number calculated for the first sector P_1. For the reference disposal facility, the following travel times and Peclet numbers are used:

Location	Travel Time (tw_1)	Peclet Number (P_1)
Intruder Well	42 years	1,300
Boundary Well	66 years	1,900
Population Well	400 years	10,000
Surface Stream	800 years	20,000

It may be pointed out that the selection of t_{wj} and P_j as the primary variables on which the migration analysis is based implicitly allows for a sensitivity analysis. Sites with differing environmental parameters may lead to similar radionuclide concentrations at the access locations. For example, similar results would be obtained if the ground-water velocity is twice as high, and the distance to the discharge access location is twice as large. Similarly, large unsaturated zone travel times would compensate for a shorter saturated zone travel time.

3.5.3 Special Cases

This section considers variations in the ground-water migration calculational procedure for three special cases: the maximum concentration case, the time dependent source analysis, and high-integrity containers.

Maximum Concentration Case

The previous equations can be used to determine radionuclide concentrations at a particular access location as a function of time. It may also be of interest to determine the maximum concentrations of a given radionuclide at a particular access location over all time.

The maximum radionuclide concentration at the particular access location considered may occur long after the initiation of the scenario. For this special case, only the reduction factor r_{tij} is affected in the above formulation and a modification of equation (G-18) is necessary to calculate the maximum concentrations. The equation utilized in this EIS is (Ref. 1):

$$f_{si} = [r_g \; r_i]/Q \qquad \text{(G-22)}$$

where r_g and Q are as defined previously, and r_i is the time independent maximum value of the migration reduction factor r_{tij}. The parameter r_i is given by the following equation.

$$r_i = \text{maximum of } [r_{i1}, r_{i2}, \ldots, r_{i10}] \tag{G-23}$$

where

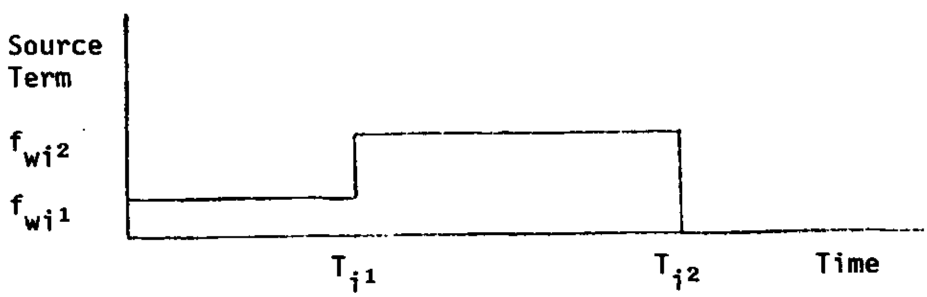
$$r_{ik} = k \times [\exp[-\lambda R t_{wk}]/(J \times T_i)] \tag{G-24}$$

where the above variables J, T_i, λ, R, and t_{wk} denote the same parameters as were defined previously.

Time-Dependent Sources

Although a disposal facility will be designed and operated so that infiltration of rainwater will be minimized, it is possible that at some time after the disposal facility is closed, active institutional controls may break down and potential inadvertent intrusion into part of the disposed wastes may occur. Similarly, a breakdown in institutional controls may lead to an increase in infiltration of rainwater into the disposed waste and a corresponding increase in the ground-water migration source term. A calculational procedure to account for this time-dependent source-term is presented below.

For the case of the time-dependent source-term analysis, the source term is assumed to increase after the end of the active institutional control period. The source term may be represented by the following histogram:



Two source terms, denoted by f_{wi1} and f_{wi2}, are calculated using equation (G-16). These source terms are used in conjunction with two source duration times denoted by (T_{i1}) and $(T_{i2}-T_{i1})$. The first source term is applicable during the duration time of T_{i1} years (equal to or less than IPO+IIC - see Section 3.1), and the second source term is applicable during a duration time equal to $T_{i2}-T_{i1}$. The second source duration time is calculated by subtracting the radioactivity that has migrated during the first duration time from the activity inventory of the site (area under the above histogram), and dividing the remaining site activity inventory by the second source term. It is calculated by the formula:

$$T_{2i} = T_{i1} + f_{wi1} \times (TDUR - T_{i1}) / f_{wi2} \tag{G-25}$$

where TDUR represents the source duration time if f_{wi1} were the source term during the entire period. In other words, TDUR is the duration time for the time-independent source-term analysis and TDUR times f_{wi1} times C_w is the entire site inventory of the radionuclide being considered.

For calculational convenience, the source term for this anlysis is taken to be equal to f_{wi1} and the effect of the increased source term after time T_{i1} is incorporated into the factor r_{tij}. After the definitions of these parameters, the following equation is applicable for the factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(JxTDUR)] \times \left\{ F_j(t) - F_j(t-T_{i1}) + (f_{wi2}/f_{wi1}) \times [F_j(t-T_{i1}) - F_j(t-T_{e=i2})] \right\} \quad \text{(G-26)}$$

where $f_j(t)$ is the function defined previously by equation (3-19), and where the variables λ, J, TDUR, T_{i1}, T_{i2}, f_{wi1}, and f_{wi2} are as defined previously. For cases where the source is depleted within the active institutional control period (TDUR is less than IPO+IIC) or for cases where the initial percolation volume at the disposal facility is greater than or equal to V1 (see Section 3.5.1), this analysis is ignored.

High-Integrity Containers

High-integrity containers are packages which are designed to preclude waste/trench water contact for long periods of time (Ref. 1). This time period may vary from a few years to several hundred yaers. The effect of this delay due to use of high-integrity containers is incorporated into the analysis by adding the delay time to all the ground-water travel times for the selected waste streams.

3.6 Exposed-Waste Scenarios

In these scenarios, some or all of the surface area of the disposed waste is assumed to be exposed through some means. The mechanism that initiates uncovering of the waste can be either the erosion of the waste cover by surface water or wind action, or intruder activities such as housing construction. Similarly, there are two exposed waste surface scenarios depending on whether the transfer agent is wind or surface waste. Furthermore, the corresponding biota access location can be either an offsite surface water body (through surface water runoff) or offsite air (through wind suspension and transport). Therefore, there are four exposed waste scenarios: intruder-air, intruder-water, erosion-air, and erosion-water.

Only those wastes that have been disposed through regular disposal designs are considered in the erosion-initiated scenarios. Waste that is layered (disposed of at the bottom of the disposal cells), and waste that is disposed of in a hot waste facility are assumed not to be exposed to the atmosphere for the erosion-initiated scenarios. However, all the wastes are considered in the intruder-initiated scenarios. The following equations are utilized to calculate human exposures resulting from these scenarios. For the water transport and access case:

$$H = \sum_i \sum_n (f_o f_{di} f_{wi} f_{si})_{wat} \, C_{wi} \, \text{PDCF-7} \qquad \text{(G-27)}$$

and, for air transport and access case:

$$H = \sum_i \sum_n (f_o f_{di} f_{wi} f_{si})_{air} \, C_{wi} \, \text{PFCF-8} \qquad \text{(G-28)}$$

where H is th 50^{th} year annual dose in mrem/year after 50 years of exposure, PDCF-7 and PFCF-8 are the radionuclide-specific pathway dose conversion factors presented in Section 2.4, and C_{wi} is the radionuclide concentration in the i^{th} waste stream. The impacts are summed over all the radionuclides (n), and over all the waste streams (i). The values of the barrier factors are presented below.

The time delay barrier factor (f_o) is defined by:

$$f_o = \exp[-\lambda T] \qquad \text{(G-4)}$$

where T is the delay time, and λ is the decay constant. For the intruder-initiated exposed waste scenarios, the delay time (T) is taken to be the period between the cessation of active disposal operations and the end of the active institutional control period. For the erosion-initiated exposed waste scenarios, it is taken to be dependent on the cover thickness utilized--i.e., it is a function of the disposal technology index IC. The following table presents the values assumed for the initiation of the erosion scenario:

IC	Delay Time
1	2000 years
2	3000 years
3	10000 years

These values are believed to be extremely conservative. Previous estimates on the erosion potential of adequately emplaced cover materials have ranged from 1,000 years to 10,000 years to erode 1 meter of soil cover (Ref. 27). After consideration of the variability of this time period, Reference 13 assumes a time of 2,000 years to erode through 2 meters of cover. This is the value utilized in this EIS.

The site design factor (f_{di}) is defined as the fraction of the exposed area that is waste and will be assumed to be independent of the properties of the waste stream considered. In this EIS, it will be taken to be proportional to the emplacement efficiency of the waste; however, in this case, the percentage of the land area in between the disposal cells that have not been utilized for waste disposal must be considered--i.e., the land-surface utilization rate (see Section 3.1). Therefore, the site design factor is taken equal to the product of the emplacement efficiency (0.75 for stacked disposal and 0.5 for other emplacement cases) with the land-surface utilization rate of the design option. (For the reference disposal facility, the land surface utilization rate is conservatively estimated to be 0.90.)

The waste form and package factor (f_{wi}) denotes the total volume of the soil-waste mixture mobilized by the transfer agent per year. In this report, it may be empirically broken down into the following components.

$$f_{wi} = E \times (A/d)_i \qquad \text{(G-29)}$$

where:

E = soil-waste mixture mobilization rate (in g/m^2-yr) which will be taken to be independent of the waste stream.

A_i = total area of the soil-waste mixture (in m^2) that can be identified with the $(i)^{th}$ waste stream.

d_i = density of the soil-waste mixture (in g/m^3) that can be identified with the $(i)^{th}$ waste stream.

This equation is conservative and is applicable for both the wind transport scenario and the surface water scenario. Specific values of the above parameters and the site selection factor f_{si} are discussed below.

3.6.1 Wind Transport Scenarios

For the intruder-initiated scenarios, the factor E can be calculated based on use of the soil-to-air transfer factor (Ref. 1). It may be taken as the time-weighted average of the dust mobilization rate resulting from construction or gardening activities such as tilling and the natural wind mobilization rate (Ref. 1).

Impacts are summed over all waste streams. To calculate the amount of radioactivity released into the air from each waste stream in the intruder-initiated exposed waste scenario, either the intruder-construction or the intruder-agriculture scenarios are used depending upon the disposal status of the waste. Regular and layered unstable waste streams are subject to the agriculture scenario, while regular stable, layered stable, and hot waste facility waste streams are subject to the construction scenario. However, only 1 percent of the layered unstable wastes are assumed to contribute to the agriculture scenario, while only 1 percent of the layered stable wastes and 0.1 percent of the hot waste facility wastes are assumed to contribute to the construction scenario. Moreover, the duration of the exposed waste scenario is modified by the duration factor of 6 hours (instead of 500 hours) for the stable wastes. Furthermore, about 1800 m^2 of waste area is assumed to be exposed continuously in the agriculture scenario with only a fraction used for gardening, and 200 m^2 of area is exposed for 500 hours for the standard construction scenario.

In order to simplify the compliacted procedure required to estimate the factor E for the above conditional cases, a basic mobilization rate is assumed to be applicable to all the cases with correction factors applied for each waste stream as appropriate for the special conditions outlined above. The basic dust mobilization rate for the intruder-initiated scenario is assumed to be 2.9×10^{-3} mg/m^2-sec (Ref. 1). For the erosion-initiated scenario, the factor E is taken as the natural wind mobilization rate of 4.1×10^{-4} mg/m^2-sec (Ref. 1).

For the erosion-initiated scenario the entire disposal site area is assumed to be exposed and A_i is calculated by dividing the volume of the waste stream being considered by the product obtained by multiplying the volumetric disposal efficiency (assumed to 6.40 m^3/m^2 for the reference disposal facility) by the surface utilization rate (0.90) and by the emplacement efficiency. The density of the soil/waste mixture is assumed to be 1.6 g/cm^3 except for those streams that are solidified using solidification scenarios A or B involving partial cement solidification. These streams are assumed to be 34% heavier.

For the wind transfer scenario, the site selection factor (f_s) is the air-to-air transfer factor (meteorological dispersion factor X/Q) (Ref. 1). For these scenarios, the number of people exposed to atmospheric releases are incorporated into the definition of the site selection factor. This results in an f_s with units of people-year/m^3.

To calculate the site selection factors, the population for the reference disposal facility (see Appendix J) is assumed to be doubled for the intruder-initiated scenario, and tripled for the erosion-initiated scenario. The number of people in each radial sector is multiplied by the corresponding atmospheric dilution factor and the results summed. The site selection factors are calculated to be 3.50×10^{-10} and 5.25×10^{-10} people-year/m^3 for the intruder-and erosion-initiated wind transfer scenarios, respectively.

3.6.2 Surface Water Scenario

Based on surface water erosion calculations (Ref. 1) the mobilization rate for the surface water scenario (i.e., the factor E in equation G-29) is calculated to be 1.84×10^2 g/m^2-year. This factor corresponds to an annual erosion rate of about 0.75 tons/acre. The other factors in the equation (i.e., A and d) remain as defined in Section 3.6.1.

The surface water site selection factor can be estimated by considering the flow rate of a nearby stream assumed to be utilized by a member of the population. In this EIS, the inverse of twice the value of the dilution factor Q previously utilized to determine ground-water impacts at the surface water access location is utilized (1.12×10^{-7} year/m^3). Twice the value is utilized to account for the increased flow conditions during heavy precipitation and subsequent heavy stream flow rates (Ref. 1).

3.7 Operational Accident Scenarios

There are two accident scenarios considered for applicability to a given stream in the impact calculations: accident-container, and accident-fire. These scenarios are described below.

3.7.1 Accident-Container Scenario

This scenario assumed that a waste container is dropped from a significant height so that the waste container breaks open and that a portion of the radioactive contents of the package is released into the air where it is transported offsite and leads to subsequent human exposure. Potential releases can be modeled as a "puff," and resulting human exposures would be over a very short time period. The potential exposures from this scenario are a strong function of the waste form--i.e., improved less dispersible waste forms lead to lower potential releases and reduced potential human exposures. The equation describing the human exposures are as follows:

$$H = \sum_n (f_o f_d f_w f_s)\ C_w\ \text{PDCF-1} \qquad \text{(G-30)}$$

where H is the 50-year dose commitment in mrem, PDCF-1 is the radionuclide specifc pathway dose conversion factor presented in Section 2.4, and C_w is the radionuclide of concentration in the waste. Impacts are summed over all the radionuclides (n).

No reduction due to decay of the radionuclides is considered, and the time delay factor f_o is assumed to be one. Similarly, no reduction due to site design and operation has been assumed and the factor f_d has also been set equal to one.

The waste form and package factor f_w is affected by the dispersibility of the material at the time of disposal. An index that can be conveniently used to represent this property is the leachability index of the waste stream (see Section 3.2.3), which also represents the solidification scenario utilized for the waste stream. The waste form and package factor is given by the following equation:

$$f_w = 10^{(I-19)} \times 10^{(I-16)} \qquad \text{(G-31)}$$

The relationship $10^{(1-I9)}$ is the accessibility multiplier discussed previously. The factor $10^{(1-I6)}$ indicates the relative dispersiblity of the solidified material after a container accident. The property values for this comparative dispersibility are based on consideration of comparative mechanical strengths (measured for compressive, unnotched Izod impact, and fragmentation tests) of waste forms (Ref. 1). If the waste is not solidified, then the dispersibility factor is assumed to be unity.

The site selection factor f_s, which is dimensionless, may be calculated by assuming that the material released is a "puff," and it stays in a puff form until it reaches the exposed individual. The following equation is utilized to calculate f_s in this EIS:

$$f_s = 1.56 \times 10^{-7} \times V \times f_r \times (X/Q) \qquad \text{(G-32)}$$

where 1.56×10^{-7} is the exposure duration factor given by the fraction of air inhaled in one intake by a man performing light activity (1.25 liters) to the annual inhalation volume (8000 m^3) (Refs. 1, 34).

The source term may be represented by the product of f_r, the fraction released per second, and V, the volume of the container. For the worst case, 0.1 percent of the waste is assumed to be released into air (the case of the PuO_2 powered accident) (Ref. 9). This release fraction is modified by the solidification status of the waste stream (see above). The volume of the container involved in the accident, V, is assumed to be 170 ft^3--the size of a typical resin liner.

For puff releases, the atmospheric dispersion factor (X/Q) for a ground level release and for a person standing in the centerline of the puff is given in reference 35 by the following formula:

$$(X/Q) = [\pi \sqrt{2\pi}\, \sigma_x \sigma_y \sigma_z]^{-1} \qquad \text{(G-33)}$$

where σ_x, σ_y, and σ_z are the distance-dependent standard deviation factors of the Gaussian puff in three directions. These sigmas, in meters, indicate the spread and dilution of the plume as a function of distance from the source. Utilizing a value of $\sigma_x = \sigma_y = 3.61$ m (based on the average wind speed at the reference facility), and a value of $\sigma_z = 2.2$ m (Ref. 35), yields a (X/Q) value of 4.42×10^{-3} sec/m^3.

3.7.2 Accident-Fire Scenario

This scenario assumes that a fire starts in a disposal cell and lasts for approximately two hours. A portion of the radioactive material is released into the air where it is transported offsite and leads to subsequent exposures of humans. Potential exposures from this scenario are a strong function of the waste form and facility design and operation. For example, a waste disposal cell in which all of the wastes are composed of compressible material (e.g., segregated disposal of compressible waste) would involve larger releases (more material to burn) than a case in which the compressible material is mixed with noncombustible waste. However, most compressible waste forms have very low levels of contamination. On the other hand, improvements in the form of the compressible material would involve lower potential releases. For example, compressible material which has been processed by incineration and solidified would involve lower potential releases than compacted compressible waste.

In this work, the accident-fire scenario is used to help assess the effect of improved waste forms and site operational practices on reducing the potential exposures from an accident involving an operational fire. Each waste stream or groups of waste streams may be tested separately using this scenario.

The equation describing the human exposures is as follows:

$$H = \sum_n (f_o f_d f_w f_s) C_w \text{ PDCF-1} \quad \text{(G-34)}$$

where H is the 50-year dose commitment in mrem, PDCF-1 is the radionuclide-specific pathway dose conversion factor discussed in Section 2.4 and C_w is the radionuclide concentration in the waste. Impacts are summed over all the radionuclides (n).

In a manner similar to the accident-container scenario, the time delay factor f_o and the site design and operation factor f_d are assumed to be unity. The waste form and package factor f_w is assumed to be equal to $0.1 \times 20^{(I4-3)}$ where I4 is the waste form flammability index (see Section 3.2.1).

The site selection factor f_s is determined by the atmospheric dispersion of the plume resulting from the accident. In this EIS, the plume resulting from the fire is assumed to travel in one direction and the exposed individual is assumed to stand in the centerline of the plume for a period of time. The following formula is used for f_s:

$$f_s = f_e \times f_r \times V \times (X/Q) \quad \text{(G-35)}$$

where f_e is the exposure duration factor (dimensionless); f_r is the release fraction per second; V is the volume of the waste involved in the fire in units of m^3; and (X/Q) is the atmospheric dispersion factor in units of sec/m^3.

In this EIS, f_e is assumed to be equal to 3.63×10^{-5} based on the ratio of the air inhaled during the time period the individual is assumed to stand in the plume of the fire (10 minutes during which a man doing light activity inhales about 0.29 m^3 of air) (Ref. 34). The fraction released per second, f_r, is assumed to be 1/7200 based on the assumed duration of the fire. This is equivalent to a fire duration time of 2 hours. The volume of waste involved in the accident is assumed to be 100 m^3 based on an estimated annual disposal volume of 50,000 m^3, two disposal cells operating simultaneously, and one disposal cell involved in the fire. The atmospheric dispersion factor (X/Q) for an accident lasting from 0 to 8 hours is given by (Ref. 35)·

$$(X/Q) = \exp[-h^2/(2\ \sigma_z)]/[\pi u\ \sigma_y\ \sigma_z] \quad \text{(G-36)}$$

where h is the release height (or the effective height of the plume at the fire source), u is the wind speed assumed to be 1 m/sec with Pasquill Stability

Class F atmospheric condition (Ref. 35) and σ_y and σ_z are as defined previously. Utilizing values for σ_y and σ_z given in Reference 35 at 100 m from the fire, and conservatively assuming ground-level releases (i.e., h=0), yields a (X/q) value of 3.62×10^{-3} and a value for f_s of 1.83×10^{-9}.

3.8 Other Impact Measures

The impact measures other than individual and population exposures associated with operation of a disposal facility include occupational exposures, land use, disposal costs, and energy use. This section considers procedures for calculating these other impact measures.

3.8.1 Land Use

Calculating the land area committed for waste disposal is a straightforward function of the total volume of the waste disposed, the waste emplacement technique (i.e., whether random, stacked, or decontainerized disposal is utilized), and the volumetric efficiency of the disposal technology considered. The volumetric efficiency is a function of site design as discussed in Section 3.1.2.

For the reference disposal facility and for disposal into a regular shallow land burial trench (design case ID=1), the disposal volume (not the waste volume) per unit disposal cell area is 6.40 m^3/m^2. Therefore, for each 3.20 m^3 of waste that is disposed randomly, 1 m^2 of area is committed. However, this land-use rate should be divided by the surface utilization rate, calculated to be 0.90 for the reference disposal facility, since for all practical purposes, the land area between the disposal cells may be considered as committed land. Incorporating this correction results in 1 m^2 of land area committed for each 2.88 m^3 of waste disposed with random emplacement. Stacked emplacement would result in 1 m^2 of land area committed for each 4.32 m^3 of waste disposed.

Similarly, for the concrete-walled trench option (design case ID=2), the volumetric disposal efficiency is calculated to be 7.00 m^3 of disposal volume per unit disposal cell area (excluding walls of the trenches). Therefore, for each 5.25 m^3 of waste disposed through stacked emplacement, 1 m^2 of cell area is committed. The land-surface utilization rate in this case is calculated to be 0.35 m^2 of disposal cell area per m^2 of available land (including walls and spaces between the trenches). Therefore, the land area committed is 1 m^2 of land for each 1.84 m^3 of waste disposed.

3.8.2 Occupational Exposures

In this appendix, the calculation of the occupational exposures at the disposal facility is performed in two phases: exposures to waste handlers during unloading and emplacement of wastes, and occupational exposures to other site personnel performing routine operational and administrative functions not directly connected with waste handling.

Occupational exposures to waste handlers are strongly dependent on the packaging of the delivered waste, the shipment mode, and the disposal procedure. Therefore, procedures for determining the occupational exposures resulting from unloading and disposal of waste are considered in the transportation impacts section of this appendix (see Section 4). Routine occupational exposures for personnel other than waste handlers are calculated in the following section.

3.8.3 Disposal Costs

Other impact measures--disposal costs, routine occupational exposures to facility personnel other than waste handlers, and energy use--are closely interrelated and are dependent on the waste volume disposed, the land-use rate, operational practices, etc. These three measures are considered in this section.

The basic unit rates (rates per unit volume or area) associated with costs (prior to multipliers to account for the cost of money, profit, inflation, etc.--see below), energy use, and routine occupational exposures at a disposal facility have been calculated in Appendices E, F, and Q. These basic unit rates are summarized in Table G.16).

The unit rates presented in Table G.16 are utilized in a computer program (OPTIONS, see Appendix H) that calculates the impact measures. Depending on the disposal facility design option selected, the status of each waste stream, I11, is determined utilizing procedures outlined in Section 3.4. Then, the volumes of waste that are unacceptable for near-surface disposal, waste disposed of through regular means, waste disposed through the layered option (if any), and waste emplaced in a hot waste facility (if any) are determined. These waste volumes, together with the selected emplacement procedure, give the respective disposal volumes required, and the disposal volumes, together with the volume utilization rates, give the respective areas involved. Then, these areas are utilized to calculate costs for design options such as alternative disposal cell covers. These unit rates are briefly discussed below.

Costs associated with the operational life of the disposal facility are divided into capital costs and operating costs as discussed in Appendix Q. Base case capital costs for the reference disposal facility are calculated from the information given in Appendix Q and include consideration of environmental investigations, licensing costs, land purchase cost, road construction, building construction, and peripheral system installation. Additional capital costs associated with implementation of a specific design option are quantified in Appendix F and added appropriately during the calculation.

The options considered during the operational life are divided into two groups: the reference system and the design options, which are subdivided into volume-dependent options and area-dependent options. For calculational convenience, these unit rates are converted to disposal volume rates since different emplacement procedures are applicable. The items considered under "other" rates include payroll, administration, equipment, etc. It is assumed that changing disposal waste volumes due to processing will not alter the rates given as "lump sum" significantly.

Table G. 16 Unit Rates for Impact Measures

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
<u>Preoperational</u>				
Reference Base Case	7,452	--	212	Lump Sum
Additive Alternatives†				
Walled Trench	594	--	--	Lump Sum
Stacking	226	--	--	Lump Sum
Segregation	1	--	--	Lump Sum
Layering	132	--	--	Lump Sum
Decontainerized Disposal	924	--	--	Lump Sum
Hot Waste Facility	260	--	--	Lump Sum
Grouting	55	--	--	Lump Sum
Intruder Barrier	281	--	--	Lump Sum
Extreme Stabilization	10	--	--	Lump Sum
<u>Operational</u>				
Reference Base Case				
Trench (-Cover)	2,341	300	200	Disposal Vol.
Regular Cover	1,420	2,400	100	Disposal Area
Other Costs	63,696	1,000	200	Lump Sum
Additive Alternatives†				
Walled Trench	74,438	700	300	Disposal Vol.
Stacking	12,758	100	100	Total Waste Vol.
Segregation	3,888	100	30	Total Waste Vol.
Layering	15,400	-100	30	Volume Disp. by Layer
Decontainerized Disposal	48,975	400	100	Volume Disp. by Decon.
Hot Waste Facility	176,979	-200	450	Volume Disp. by HWF
Grouting	72,405	2,550	800	Grout Volume
Sand Backfill	2,370	--	185	Sand Volume
Cover Options				
Thick	15,524	2,400	150	Disposal Area
Intruder Barrier	103,854	2,400	300	Disposal Area
Moderate Stabilization	3,465	4,800	300	Disposal Area
Extreme Stabilization	33,345	4,800	600	Disposal Area

Table G.16 (continued)

Activity	Cost (thousand 1980 $)	Occupational* Exposure (person-mrem)	Energy Use (thousand gallons)	Units**
Postoperational				
Closure Period				
Regular Closure	1,010	500††	60	Lump Sum
Extensive Closure	3,025	1,000	60	Lump Sum
Institutional Period#				
Low Care Level				
Years 1-10	150	--	2	Per Year
Years 11-25	63	--	2	Per Year
Years 26-100	51	--	2	Per Year
Medium Care Level				
Years 1-10	303	--	6	Per Year
Years 11-25	150	--	6	Per Year
Years 26-100	63	--	6	Per Year
High Care Level				
Years 1-10	440##	--	10	Per Year
Years 11-25	303	--	10	Per Year
Years 26-100	150	--	10	Per Year

*Occupational exposures associated with operations other than waste unloading and disposal.

**Lump sum items are assumed to be independent of the waste volume; disposal volume dependency is for 1 million m^3 of disposal (not waste) volume; grout volume dependency is for 1 million m^3 of grout injected; sand volume dependency is for 1 million m^3 of sand backfill; disposal area dependency is for 1 million m^2 of trench cover area.

†All these rates for alternatives are incremental rates in addition to the rates given for the reference system.

††Regular closure is assumed to last 2 years; extensive closure is assumed to last four years. Both cases assume 5,000 person-hours of field work per year in an average radiation field of 0.05 mR/hr.

#These costs are basic costs not considering inflation or interest. Details for complete calculation of the institutional period costs, including consideration of inflation and interest, can be found in Appendix Q. The formulas given in that appendix are incorporated into the cost calculation procedure.

##To this cost, a contingency cost is added which depends on the soil conditions: $367,000 for medium-permeability soils; $168,000 for high-permeability soils; and, $1,007,000 for low-permeability soils.

The second group of options (termed additive alternatives in Table G.16) result from the application of the available design options (ID, IS, IE, IL, IH, and IG) discussed in Section 3.1 in a straightforward manner. These rates are also estimated from a wider range of design and technology options considered in Appendix F. The rates given in Appendix F are normalized, however, to one-million m^3 of waste volume for calculational convenience. Similarly, the grouting option rates are for one-million m^3 of grout injected, since the option may be exercised with either random or stacked disposal, etc. One consequence of the application of the hot waste facility option is that the total routine occupational exposures are estimated to go down as a result of increased shielding afforded by the special facility; this effect is expressed by giving a negative occupational exposure to the hot waste facility. The third group of operational options result from the application of cover-related options (IC, IX) discussed in Section 3.1. These options are area-dependent. For calculational convenience they also have been normalized to one-million m^2.

All these options are additive. As an example, the preoperational and operational costs resulting from disposal of 900,000 m^3 of waste (all found acceptable for near-surface disposal) in the reference facility with a volume efficiency of 5 m^3/m^2, with stacked emplacement (0.75), with grouting, with a thick cover, and with maximum stabilization are tabulated in Table G.17. Occupational exposures and energy use are calculated in a similar manner.

These costs, however, are multiplied with two conversion factors to account for cost of money, inflation, and other financial considerations. These multipliers are presented below. A more detailed explanation of the derivation of these multipliers can be found in Appendix Q.

For capital costs, the following items are applicable:

Item	Factor
Indirect Costs	1.73
Fixed Charge	5.00
Profit	1.20

Indirect costs result from interest during construction, contingency, and other costs such as miscellaneous overhead expenses, insurance, sales tax, etc. The fixed charge results from an assumed 25% charge on capital over the 20-year operating life of the facility. These three items result in a multiplier of 10.38 for the preoperational capital costs. For the operational costs, the following items are applicable:

Item	Factor
Contingency	1.30
Profit	1.20

This results in a multiplier of 1.56 for the operational costs. These multipliers may be illustrated through use of the example presented in Table G.17. Using these multipliers with the preoperational capital costs of $7,810,000 and the operational cost of $107,953,000 yields a total preoperational and operational cost of about $249,475,000 in 1980 dollars.

Postoperational costs (composed of closure costs and long-term care costs) are calculated using the following two equations. For the closure costs, the following equation is applied.

$$\text{Closure Costs} = C_{80} \times L \times (1+j)^L \left\{ f + \frac{i}{[(1+i)^L - 1]} \right\}$$

where C_{80} is the closure cost presented in Table G.16, L is the facility life in years, f is an annual fee for a surety bond which assures availability of closure funds (1.5% is generally used in this EIS), j is the inflation rate (9% is generally used in this EIS), and i is the interest rate (10% is generally assumed). For long-term care costs, the following equation is applicable:

$$\text{LTC Cost} = PV_{80} \times \frac{L \times (1+j)^M \times i}{[(1+i)^L - 1] \times (1+i)^C} \qquad \text{(G-37)}$$

where LTC stands for long-term care, L is the site operational life in years, C is the closure period in years, M is L+C, i is the interest rate, j is the inflation rate, and PV_{80} is given by the following equation:

$$PV_{80} = C_a \sum_{n=1}^{10} R^n + C_b \sum_{n=11}^{25} R^n + C_c \sum_{n=25}^{100} R^n \qquad \text{(G-38)}$$

where R is the ratio (1+j)/(1+i). The parameters C_a, C_b, and C_c are the annual costs given in Table G.16 for the long-term care costs during the years 0-10, 11-25, and 26-100, respectively. The cost rate C_a may include a contingency cost as referenced in Table G.16 and discussed in more detail in Appendix Q.

4.0 TRANSPORTATION IMPACTS

This section discusses the calculational procedures used to determine impacts associated with transportation of waste to the disposal facility. The impact measures developed in this report include: cost; occupational exposures associated with loading, transporation, and unloading of the waste; population exposures associated with transportation; and energy use. Section 4.1 presents the packaging and shipping assumptions utilized in the calculations. Transportation costs and other impact measures are presented in Sections 4.2 and 4.3, respectively.

Table G.17 Illustrative Calculation

Assumptions: 900,000 m^3 of waste
stacked, grouted, thick cover,
maximum stabilization,
disposal efficiency of 5 m^3/m^2

Disposal Volume = 900,000/0.75	= 1,200,000 m^3
Empty Disposal Space = 1,200,000x(1-0.75)	= 300,000 m^3
Disposal Area = 1,200,000/5	= 240,000 m^2

Preoperational Costs	
Reference System	$ 7,452,000
Stacking	138,000
Grouting	220,000
Total Preoperations:	$ 7,810,000
Operational Costs	
Reference System	
Trench Construction	$ 2,810,000
Regular Cover	341,000
Other Costs	63,696,000
Additive Alternatives	
Stacking Option	7,528,500
Grouting Option	12,457,500
Thick Cover	4,224,000
Maximum Stabilization	16,896,000
Total Operations:	$107,953,000

4.1 Packaging and Shipping Assumptions

Potential impacts (e.g., occupational exposures, population exposures, and costs) incurred during transportation of waste to the disposal facility and during subsequent unloading and emplacement operations are influenced by a number of interrelated factors. These interrelated factors increase the complexity of the impacts analyses and arise from the greatly variable nature of LLW and LLW transportation. For example, LLW can be generated in a great variety of forms and can range from wastes having very low to moderately high radioactivity concentration levels. In addition, a range of waste container types and sizes are presently available and in use.

For the purposes of this EIS, some simplifying assumptions regarding waste packaging and transportation are made based upon past experience. These assumptions include those in the following areas:

- The degree of care required for waste handling and transportation (package surface radiation levels);
- Container sizes and types; and
- The shipment mode (vehicles and overpacks used).

Additional information regarding these simplifying assumptions is provided below.

4.1.1 Surface Radiation Levels

Radiation levels at the waste package surfaces affect the care required in handling of wastes and the shielding that may be required during transportation. For the purposes of this appendix, the waste streams are generically classified into three categories according to the level of care assumed to be required to handle each waste stream:

- Regular care
- Special care
- Extreme care

Packaging sizes and packaging procedures are instrumental in determining the self-shielding afforded by some of the waste packages. Howeever, there can be significant variations in the level of care required for each package due to variations in the specific activities of the wastes within a given stream. For this analysis, the level of care is assumed to be independent of waste package shape and volume. The relative level of care is assumed to depend only on the total specific activity contained in the waste package and the presence or absence of high-energy gamma-emitting radionuclides.

Each waste stream is denoted by an index representing the type of activity with regard to high-energy gamma-emitting radionuclides. Waste streams containing significant quantities of fission products (most notably Co-60, Nb-94, and Cs-137) are denoted as the first category. Waste streams containing very little high-energy gamma emitters (and consequently all requiring a "regular" level of care) are denoted as the third categroy. Other streams in between these two are denoted as the second category:

Category 1 : Fission product wastes
Category 2 : Other wastes
Category 3 : All regular care wastes

In addition to these categories, the specific activity, and therefore the required level of care, for a given waste stream varies significantly. For example, surface radiation readings of similarly sized LWR resin packages varying over two or three orders of magnitude have been observed (Ref. 17). To account for this normal variation, Table G.18 is used to estimate the fraction of each waste stream that requires a specific level of care based on the total specific activity of the waste stream.

Table G.18 Distribution Between Care Level Required with Type and Specific Activity of Waste

Total Specific Activity (Ci/m^3)			Percent Waste Stream Volume in Each Handling Category		
Type 1	Type 2	Type 3	Regular	Special	Extreme
<0.01	<0.1	All	100	--	--
.01-.1	.1-1		80	20	--
.1-1	1-10		40	50	10
1-10	>10		20	60	20
10-100			10	50	40
>100			--	20	80

The values in this table are estimated guided by standard health-physics "rules of thumb" calculations for determining the surface radiation level of a waste package--e.g., the 6CEn formula (Ref. 36). For example, for waste in Category 1 with about 2 Ci/m^3 of activity, 20% of the waste volume is assumed to require regular care, 60% of the waste volume is assumed to require special care, and the remaining 20% is assumed to require extreme care. According to the 6CEn formula, assuming that all the radioactivity is Co-60 and the waste package is a 55-gallon drum, this waste may have a radiation reading of about 6 R/hour. For waste in Category 2 with about 0.2 Ci/m^3 of activity, 80% of the volume is assumed to require regular care, and the remaining 20% is assumed to require special care. All wastes in Category 3 are assumed to require regular care.

After determining the fraction of waste volume in each stream that requires a specific level of care, the waste is assumed to be packaged and shipped. The packaging and shipping assumptions for these fractions are discussed below.

4.1.2 Packaging Parameters

There are many different types of packaging currently utilized for shipment and disposal of LLW (Refs. 37, 38). These packages include wooden boxes of various sizes ranging from 10 ft^3 to 248 ft^3, 55-gallon drums, and liners (usually carbon steel) of various sizes ranging from 16 ft^3 to 200 ft^3 which fit into transport casks. For the generic analyses performed in this EIS for determining transportation and disposal impacts, these packages were generalized into five different categories:

- Large wooden boxes - 128 ft^3
- Small wooden boxes - 16 ft^3
- 55-gallon drums - 7.5 ft^3
- Small liners - 50 ft^3
- Large liners - 170 ft^3

The primary rationale for selecting these sizes is that they appear to be the most widely used sizes, and that they may be used to represent an average of other packages. For example, the 128 ft^3 box is the most commonly used (4'x4'x8') size to ship low-specific-activity (LSA) waste; the 170 ft^3 liner is the commonly available 6'x6' right-circular cylinder.

During the transportation analysis, for regular- and special-care wastes, all five methods of packaging are assumed to be acceptable. The high-activity of extreme-care wastes renders the use of boxes for packaging unacceptably inconvenient; therefore, all waste that is classified "extreme care" has been assumed to be packaged in either drums or liners which are remotely manipulated for loading and off-loading.

The distribution of these package types for each waste stream have been assumed using available shipping and survey data (Refs.1, 37-40), and are presented in Table G.19.

4.1.3 Mode of Shipment

Similar to the numerous different types of available waste packages, there may exist many different shipment modes ranging from rail and barge transport to truck transport. Many different types of overpacks may be used that depend on the handling and shielding requirements for individual waste packages (Refs. 37, 39).

In this EIS, only truck transport is considered because trucks are the most commonly used mode of transportation and truck transport is radiologically the most conservative case. Vehicles and overpacks utilized in truck shipments depend on package sizes as well as package shielding requirements. In this EIS, six different types of transport vehicles and overpacks are assumed:

1. Vans
2. Flatbed trailers
3. Shielded trailers
4. Large shielded casks
5. Small shielded casks
6. 1-drum shielded casks

Table G.19 Packaging of LLW for Waste Spectrum 1 (percent of volume packed in containers)

Waste Stream	Large Boxes	Small Boxes	55-g Drums	Small Liners	Large Liners
LWR Process Waste Group	--	--	69	15	16
Trash Group (except P- & B-NCTRASH)	23	8	69	--	--
P- & B-NCTRASH	--	--	100	--	--
Low Specific Activity Waste Group (except F- & U-PROCESS)	--	2.5	97.5	--	--
F- & U-PROCESS	--	--	100	--	--
Special Waste Group	--	--	100	--	--

*Other distributions depending on the spectrum may be imposed on the individual waste streams.

Large casks are used for transporting either large liners or fourteen 55-gallon drums, while small casks are used for transporting either small liners or six 55-gallon drums. These casks are transported to the disposal facility via flatbed trailers.

The use of particular types of vehicles and overpacks is strongly influenced by the level of care required for safe waste handling and transport of the waste packages. Vans are assumed to be suitable for all types of containers in the regular care category, with the exception of large liners which require casks. In addition, flatbed trailors are assumed to be used only for large boxes of regular-care wastes. Shielded trailers are assumed to be required for large and small boxes and drums of special-care wastes. Some of these small boxes and drums, as well as large and small liners, are assumed to require casks. Casks are assumed to be the only acceptable mode of transport for extreme-care wastes.

The percentage use of different vehicles and overpacks for each container have been estimated considering records of waste shipments delivered to the Maxey Flats, Kentucky disposal facility (Ref. 1). A tabular listing of the basic assumptions made for the transportation of wastes is presented in Table G.20. Extreme care liner shipments have been assumed to be "overweight" shipment since these require significant shielding for transportation purposes. These are also designated in Table G.20 (Refs. 1, 39).

Table G.20 Packaging and Shipment Mode Parameters

Care Level and Container	Overpack*	Per Shipment: Pieces	Per Shipment: Percent Volume	Man-Minutes for Disposal Per Container: Random	Man-Minutes for Disposal Per Container: Stacked
Regular Care					
Large Box	Van	3	24	200	240
	FB	4	76	74	120
Small Box	Van	36	100	16	24
Drum	Van	70	100	6	24
Small Liner	Van	11	100	136	165
Large Liner	LC	1	100	1200	1440
Special Care					
Large Box	ST	3	100	300	360
Small Box	ST	36	96	26	39
	LC	6	4	250	300
Drum	ST	70	48	10	24
	LC	14	51	86	175
	SC	6	1	200	312
Small Liner	SC	2	100	600	720
Large Liner	LC	1	100	1200	1440
Extreme Care					
Drum	SC	6	51	200	312
	1D	1	49	600	720
Smaller Liner	SC**	2	100	600	720
Large Liner	LC**	1	100	1500	1800

*FB = flatbed trailer; ST = shielded trailer; LC = large shielded cask; SC = small shilded cask; 1D = 1-drum shielded cask.

**These shipments are estimated to be overweight.

4.2 Costs

Transportation costs include a mileage charge (including fuel surcharge), a cask use charge (rental), and an overweight shipment transportation charge.

The mileage charge is calculated by estimating the total shipment miles required (including return trip mileage for casks). For the reference facility, an average of 400 miles per one-way shipment is assumed. The basic transportation charge depends on the one-way distance and is estimated according to the following table (Ref. 1).

One-Way Distance	One-Way ($/mile)	Round Trip ($/mile)
< 400 miles	1.69	1.25
400-100 miles	1.47	1.14
> 1000 miles	1.17	1.08

Added charges, which become significant for extreme-care shipments, include a fuel surcharge (15% of the basic cost) and an overweight charge. The amount of the overweight charge depends on the maximum gross vehicle weight (GVW) allowed in states through which the shipment passes. Any overweight condition up to 85,000 lbs. is charged at about $0.21/mile plus the permit charges for each state (about $100 per 600 miles). A GVW of over 85,000 lbs. is assumed to be additionally charged $0.005 per mile per hundred pounds (cwt) over this limit. For a shipment of 96,000 lbs., which is a minimum for an extreme-care cask, the charges for an example one-way trip of 600 miles would be as follows:

Basic cost @ $1.14/mile	$1,368.00
Fuel surcharge @ 15% of charge	205.00
Overweight charge @$0.21/mile	126.00
Overweight surcharge @ $0.005/cwt/mile	330.00
Five overweight permits @ $20.00/state	100.00
Total:	$2,129.00
Per Mile:	$ 3.55

The cask-use charge calculation assumes an average turnaround time of 4 days. Cask rental rates vary depending on the size and weight of the cask required. They average $250/day for shielded casks enclosing high-activity LLW, and range down to $110/day for an unshielded 120 cubic foot capacity cask (Ref. 9). The rental rates also vary with the specific type of nuclear material the cask is licensed to carry and the accompanying performance standards the cask must satisfy.

4.3 Other Impacts

In addition to costs, three other impact measures resulting from LLW transportation are calculated in this report: energy use, occupational exposures, and population exposures. These impacts are reviewed in this section.

The energy use is calculated based on the total shipment miles, including empty cask return trips, and an average fuel consumption rate of 6 miles/gallon.

The occupational and population exposures incurred during transportation are calculated based on total loaded miles and the number of loaded shipments. The concept of loaded miles and shipments allows the miles in which the vehicle is empty because it is on a return trip to be eliminated from consideration. Occupational and population exposures are calculated separately from those resulting during transit, and those resulting from stopovers during the trip. Occupational exposures during stopovers are estimated by assuming two drivers. Each inspect the overpack for 3 minutes (10 mR/hr radiation field at the surface of the overpack), and walk around the overpack for 30 minutes (1 mR/hr radiation field at about 3 ft). This yields 2 person-mrem per stop for each shipment. The population exposure during stopovers is estimated in Reference 1, and also yields about 2 person-millirem per stop for each shipment. To estimate occupational and population exposures during transit, the values per shipment-mile given in WASH-1238 are utilized (Ref. 8). These exposure rates are summarized below.

	Population Doses (person-mrem)	Occupational Doses (person-mrem)
During Transit		
Per Shipment Mile	0.018	0.02
During Stopover		
Per Shipment	2.0	2.0

Occupational exposures resulting from the loading of the waste packages are also included in the transportation occupational exposures. These occupational exposures are calculated based on two factors: the man-minutes required to load each container, and the radiation field associated with the level of care required for each container. The man-minutes for stacked disposal shown in Table G.20 is assumed to be applicable for loading of the wastes. The radiation levels associated with the handling environment (not the package surface radiation levels) for each level of care are assumed to be as follows:

Level of Care	Radiation Level (uR/hr)
Regular	750
Special	1800
Extreme	2200

The calculation of occupational exposures to waste handlers is also straightforward based on estimates of personnel time required for unloading and disposal of the wastes. These estimates are presented in Table G.20. Other parameters necessary for the computations are the radiation fields associated with the handling environment that the workers are exposed to. These fields are assumed to be a function of the care level of the package and whether the disposal is random or stacked. The following table presents these assumptions:

Level of Care	Radiation Level (uR/hr) Random	Stacked
Regular	500	750
Special	1200	1800
Extreme	2000	2200

Impacts calculated from these estimates are added to disposal facility occupational exposures calculated in Section 3.8.3 for disposal facility personnel other than waste handlers. Decontainerized disposal of waste is assumed to require twice the time needed for stacked handling for those packages that are to be disposed in this manner.

5. WASTE PROCESSING IMPACTS

This section discusses the calculational procedures utilized to determine the impact measures associated with processing the waste streams. These impact measures include population exposures, occupational exposures, costs, and energy use. The processing options considered in this EIS and the unit rates for costs, person-hours, and energy use for these processing options are presented in Appendix D. Based on this information and using an additional waste stream index, denoted by I10, the processing impacts are calculated for respective cases utilizing the assumptions and procedures presented in this section.

5.1 Waste Processing Index

The variations in the processing technologies applied to a given stream, which affect the calculation of the impact measures, include the volume reduction process type, the volume increase process type, the location of the processing, and the environment in which the processing takes place. For calculational convenience, the waste processing option applicable to each waste stream for each waste spectrum has been digitized and is called the waste processing index, denoted by I10 (see Section 3 for other waste form behavior indices).

The index I10 is a four-digit number with each digit denoting a specific procedure for calculation of the impact measures. These digits cumulatively correspond to a specific case. The meaning of the digits that make up the processing index are presented in Table G.21. The processing indices applied to each waste stream for each spectrum are presented in Table G.22.

The impact measures calculated represent impacts in addition to those associated with waste spectrum 1.

Table G.21 Waste Processing Index - I10

	Value	Meaning
First Digit - P	0	No Volume Reduction
	1	Regular Compaction
	2	Improved Compaction
	3	Hydraulic Press
	4	Evaporation
	5	Pathological Incineration
	6	Small Calciner
	7	Large Calciner
Second Digit - S	0	No Solidification
	1	Solidification Scenario A
	2	Solidification Scenario B
	3	Solidification Scenario C
Third Digit - L	0	No Processing
	1	Processing by the Waste Generator
	2	Processing at a Regional Processing Center
Fourth Digit - E	0	No Incineration
	1	Urban Environment
	2	Rural Environment

Table G.22 Processing Index (I10) Breakdown

Waste Streams	SPECTRUM 1				SPECTRUM 2				SPECTRUM 3				SPECTRUM 4			
	P	S	L	E	P	S	L	E	P	S	L	E	P	S	L	E
P-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
P-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-FCARTRG	0	1	1	0	0	2	1	0	0	3	1	0	0	3	1	0
B-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
B-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
B-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
P-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
B-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
B-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
F-COTRASH	0	0	0	0	1	0	1	0	6	3	1	1	6	3	1	1
F-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0
I-COTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
I+COTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-SSTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+SSTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-LOTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+LOTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
F-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I-LQSCNVL	0	0	1	0	1	0	1	0	5	3	1	1	5	3	1	1
I+LQSCNVL	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-ABSLIQD	0	0	1	0	0	2	1	0	0	3	1	0	5	3	1	1
I+ABSLIQD	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-BIOWAST	0	0	1	0	0	0	1	0	5	3	1	1	5	3	1	1
I+BIOWAST	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
N-SSWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-LOWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-NFRCOMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-DECONRS	0	3	1	0	0	3	1	0	6	3	1	2	6	3	1	2
N-ISOPROD	0	2	1	0	0	3	1	0	0	3	1	0	0	3	1	0
N-HIGHACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TRITIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-SOURCES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TARGETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 Population Exposures

For the purposes of calculation of population exposures in this EIS, only incineration is assumed to result in significant atmospheric releases to the environment. The fraction of the radioactivity released depends on the type of incinerator, the controls on the off-gas system, and the radionuclide.

In this EIS, the fractions of the total input activity released to the atmosphere are assumed to be the following (Ref. 1):

	Release Fraction and Incinerator Type	
Nuclide	Pathological	Calciner
H-3	0.90	0.90
C-14	0.75	0.25
Tc-99	0.01	0.001
I-129	0.01	0.001
All Others	2.5×10^{-4}	2.5×10^{-6}

In this table, a calciner/incinerator is assumed to have better off-gas controls than a pathological incinerator. Most of the incinerated tritium is released as water vapor. Although some of the tritiated water vapor may deposit in very close vicinity of the release point due to condensation, this effect is conservatively not considered in this report. Carbon-14 is usually released as tagged CO, CO_2, and other combustion gases. Tc-99 and I-129 are usually considered as semivolatile nuclides that are harder to control than particulates. All other radionuclides are assumed to be particulates, and particulate release fractions are applied. These fractions are also used in modifying the waste concentrations for tritium and carbon-14. Release fractions for other radionuclides are conservatively assumed not to affect the radionuclide concentrations in the final product.

The final assumptions on population exposure calculations involve (1) the environment that is affected by the processing and (2) the dose conversion factors. It is assumed that institutional facilities are in an urban environment and all other facilities (including the regional processing center) are in a "rural" environment. Correspondingly, a site selection factor (sum of the products of the atmospheric diffusion factor and the number of people affected in each corresponding radial distance--see Reference 1) of 1.75×10^{-10} person-year/m^3 is applied to a rural environment, and ten times this value (i.e., 1.75×10^{-9} person-year/m^3), is applied to an urban environment.

The pathway dose conversion factor used in calculating the population doses are those applicable to the erosion-air transport scenario,--i.e., PDCG-8 presented in Table G.10.

5.3 Other Impacts

Other impacts are calculated based on the unit rates (cost, labor-hours, and energy use) that have been assumed based upon information presented in References 3 through 8 for selected waste processing options. These unit rates are summarized in Table G.23 and are discussed below.

Table G.23 Summary of Processing Unit Impact Rates

Process	Cost (1980 $)	Labor (hours)	Energy (gal of fuel)	Units
Compaction				
Regular	335	15	4.6	Per m^3 of Input
Improved	503	15	4.6	
Hydraulic Press	1006	15	4.6	
Evaporation	690	4.42	56.3	Per m^3 of Input
Incineration				
Pathological	2060	8	116	Per m^3 of Input
Calciner (small)	1938	6.12	129	
Calciner (large)	1039	5.35	72	
Solidification				
Scenario A	1282	24	40	Per m^3 of Output
Scenario B	1873	24	40	
Scenario C	2445	24	40	

In this EIS, the energy use is expressed in units of gallons of fuel, and the factors utilized in the calculations to convert from electrical energy and thermal energy to gallons of fuel are 40.6 kW-hr per gallon of fuel and 138.690 BTU per gallon of fuel, respectively (Ref. 5). Another assumption involving energy use is that 10 percent of the first year capital cost in 1980 dollars has been assumed to be attributable to fuel use at a rate of $1/gallon.

Occupational exposures resulting from waste processing occur primarily as a result of repair and maintenance activities on the waste processing equipment; however, it is difficult to estimate the exposures resulting from equipment repair and maintenance processing in a generic manner. This is due to the wide variations in the design of processing equipment as well as variations in the effectiveness of administrative controls on waste generators. In this EIS, all LWR waste processing is assumed to take place in a radiation field of 0.5 mR/hour, and all other waste processing is assumed to take place in a radiation field of 0.1 mR/hour. Based on these assumed radiation fields and the labor hours required to process unit volumes of waste, it is straightforward to calculate the occupational exposures.

Another factor which affects the impact measures and which has been considered in the impact calculations is the "savings" resulting from the change in waste volume. This is represented by differential costs in packaging and storage, differential savings in occupational exposures resulting from handling less waste in storage, and differential savings in energy. These unit rates are assumed based on information presented in References 1 and 41. The "savings" applied to each stream based on per unit (m^3) net reduced volume are assumed to be \$210, 4 person hours, and 0.4 gallons of fuel. If the waste processing results in additional volumes of waste (e.g., solidification), then these savings become additional impacts.

The unit rates for costs, energy use, and labor-hours assumed for the processes considered in this report--compaction, evaporation, incineration, and solidification--are presented in Reference 1.

REFERENCES

1. Oztunali, O., et al., Data Base for Radioactive Waste Management. Volume 3. Impact Analysis Methodology Report, NUREG/CR-1759, being prepared by Dames & Moore for U.S. Nuclear Regulatory Commission.

2. Science Applications Inc., Systems Analysis of Shallow Land Burial Project, NUREG/CR-1963, prepared for U.S. Nuclear Regulatory Commission, 1980.

3. Aikens, E. E., et al., Generic Methodology for Assessment of Radiation Doses from Groundwater Migration of Radionuclides in LWR Wastes in Shallow Land Burial Trenches, prepared by Dames & Moore for Atomic Industrial Forum, Inc., AIE/NESP-013, December 1977.

4. U.S. Department of Energy, Final Environmental Impact Statement Management of Commercially Generated Radioactive Waste, DOE/EIS-0046F, October 1980.

5. U.S. Atomic Energy Commission, Directorate of Regulatory Srandards, Environmental Survey of the Nuclear Fuel Cycle, WASH-1248, 1973.

6. Oztunali, O., et al., Data Base for Radioactive Waste Management. Volume 2. Waste Source Options, NUREG/CR-1759, being prepared by Dames & Moore for U.S. Nuclear Regulatory Commission.

7. Council on Environmental Quality, Executive Office of the President, Regulations For Implementing the Procedural Provisions of the National Environmental Policy Act, 40 CFR Parts 1500-1508 45 FR 55978-56007, November 29, 1978.

8. U.S. Atomic Energy Commission, Directorate of Regulatory Standards, Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plants, WASH-1238, December 1972.

9. U.S. Nuclear Regulatory Commission, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, January 1977.

10. International Commission on Radiological Protection (ICRP), Radionuclide Release into the Environment: Assessment of Doses to Man, ICRP Publication 29, 1978.

11. Denham, D. H., et al., Radiological Evaluation for Advanced Waste Management Studies, Battelle Pacific Northwest Laboratories Report No. BNWL-1764, 1973.

12. Oztunali, O., et al., Data Base for Radioactive Waste Management, Volume 1. Review of Past Disposal Practices, NUREG/CR-1759, being prepared by Dames & Moore for U.S. Nuclear Regulatory Commission.

13. Clancy, J., Trench Gas Study at the Beatty Low-Level Radioactive Waste Disposal Site, prepared for Nuclear Engineering Company, Inc., Louisville, Kentucky, by Dames & Moore, October 1978.

14. Clancy, J., H. Tuchfeld and G. Re, Mass Balance Study of Maxey Flats Low Level Waste Disposal Site - Task 5 Report - Evaporator Effluent and Trench Gas Studies, prepared for Commonwealth of Kentucky, Department for Human Resources, by Dames & Moore, April 1980.

15. Task Group on Lung Dynamics for Committee II of the International Commission on Radiological Protection," Health Physics 12, 173, 1966.

16. International Commission on Radiological Protection (ICRP), The Metabolism of Compounds of Plutonium and Other Actinides, ICRP Publication 19, Pergamon Press, Oxford, 1972.

17. International Commission on Radiological Protection (ICRP), Report of Committee II on Permissible Dose From Internal Radiation, ICRP Publication 2, 1959.

18. U.S. Nuclear Regulatory Commission, Office of Standards Development, Draft Regulatory Guide 1.109. Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I. Revision 1, October 1977.

19. U.S. Nuclear Regulatory Commission, Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake, NUREG-0172, November 1977.

20. Beck, H. and G. de Planque, The Radiation Field In Air Due to Distributed Gamma Ray Sources in the Ground, U.S. Atomic Energy Commission, Health and Safety Laboratory Report No. HASL-195, 1968.

21. Lederer, C. M., J. M. Hollander, and I. Perlman, Table of Isotopes, Sixth Edition, John Wiley & Sons, Inc., New York, 1967.

22. Kocher, D. C., Dose-Rate Conversion Factors for External Exposure to Photon and Electron Radiation from Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities, prepared for U.S. Nuclear Regulatory Commission by Oak Ridge National Laboratory, NUREG/CR-0494, 1979.

23. Adam, J. A. and V. L. Rogers, A Classification System for Radioactive Waste Disposal - What Waste Goes Where?, NUREG-0456, June 1978.

24. Rogers, V. L., A Radioactive Waste Disposal Classification System, prepared by Ford, Bacon and Davis Utah Inc. for U.S. Nuclear Regulatory Commission, NUREG/CR-1005, September 1979.

25. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, A Task Force Report, NUREG-0116 (Supp. 1 to WASH-1248), October 1976.

26. U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Final Programmatic Environmental Impact Statement Related to Decommissioning and Disposal of Radioactive Wastes Resulting from March 28, 1979 Accident, Three Mile Island Nuclear Station, Unit 2, NUREG-0683, March 1981.

27. Healy, J. W., and J. C. Rodgers, Limits for the Department of Energy Transuranic Wastes, Los Alamos Scientific Laboratory, LA-UR-79-100, January 1979.

28. McMahon, L. A. and P. E. Pereira, McGraw-Hill's 1981 Dodge Guide to Public Works and Heavy Construction Costs, McGraw-Hill Information Systems Company, New York, 1981.

29. Hamilton, J. L. and O. I. Oztunali, Comparative Evaluation of Radionuclide Transport Models from Shallow Land Burial Grounds, Dames & Moore Report, prepared for Union Carbide Corporation Nuclear Division, Subcontract No. 1 7273, October 1979.

30. Appel, C. A., and J. D. Bredehoeft, Status of Ground-Water Modeling in the U.S. Geological Survey, Geological Survey Circular 737, Department of the Interior, Geological Survey, 1976.

31. Abramowitz, M. and I. A. Stegun, Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, National Bureau of Standards, Applied Mathematics Series-55, December 1965.

32. Staley, G. B., G. P. Turi, D. L. Schreiber, U.S. Nuclear Regulatory Commission, Radionuclide Migration From Low-Level Waste: A Generic Overview, in Management of Low-Level Radioactive Waste, Volume 2, Pergamon Press, New York, 1979.

33. Schneider, K. J., and A. M. Platt, High-Level Radioative Waste Management Alternatives, Battelle Pacific Northwest Laboratories, Report No. BNWL-1900, May 1974.

34. International Commission on Radiological Protection (ICRP), Report of the Task Group on Reference Man, ICRP Publication 23, 1975.

35. U.S. Nuclear Regulatory Commission, Office of Standards Development, Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors, March 1976.

36. U.S. Department of Health, Education and Welfare, Radiological Health Handbook, Revised Edition, January 1970.

37. Phillips, J., et al., A Waste Inventory Report for Reactor and Fuel Fabrication Facility Wastes, ONWI-20, prepared by NUS Corporation for Battelle Office of Waste Isolation, March 1979.

38. Mullarkey, T. B., A Survey and Evaluation of Handling and Disposing of Solid Low-Level Nuclear Fuel Cycle Wastes, AIF/NESP-0080, prepared by NUS Corporation for Atomic Industrial Forum, Inc., October 1976.

39. Anderson, R. L., et al., Institutional Radioactive Waste, NUREG/CR-0028, prepared by University of Maryland for the U.S. Nuclear Regulatory Commission, March 1978.

40. Beck, T. J., L. R. Cooley, and M. R. McCampbell, Institutional Radioactive Wastes, 1977, NUREG/CR-1137, prepared by University of Maryland, October 1979.

41. Draft Report, Volume Reduction Techniques in Low-Level Radioactive Waste Management, prepared for U.S. Nuclear Regulatory Commission by Teknekron, Inc., February 1979.

Appendix H

ALTERNATIVES ANALYSES CODES

This appendix presents and discusses the computer programs written to calculate the impact measures associated with the management of low-level radioactive waste (LLW). The appendix considers three phases of waste management (see Appendix G) which may result in impacts: waste processing, transportation, and disposal. The impact measures are calculated utilizing: (1) the information on the waste characteristics presented in Appendix D, (2) the data and assumptions on disposal techologies and disposal site environment presented in Appendices E, F, and J, and (3) the impact calculation methodologies presented in Appendix G.

The analyses are applied to a number of alternatives for waste form and packaging, disposal facility regional location, disposal facility design and operation, and institutional controls to determine performance objectives and technical requirements for acceptable disposal of the wastes and to determine the environmental impacts of selected alternatives. Five quantifiable impact measures have been selected for calculation in this appendix: dose to members of the public (individual and population), occupational exposures, costs, energy use, and land use (see Appendix G).

Section 1 is an introduction to the appendix and provides a discussion of the applicability of the analyses to generic versus specific disposal technologies, and presents the background rationale for separating the analyses into the components presented in the subsequent sections. Following this section, discussions of five codes which have been developed for use in this EIS are presented in Sections 2 through 5. Included in the discussions are the overall assumptions, general structures of the computer codes employed, and examples of the results of the codes. General parameters common to all the codes and a listing of the computer programs and the data bases employed are presented in Section 6. The computer codes were developed by Dr. O. I. Oztunali, et al., of the firm of Dames & Moore, and this appendix is mostly excerpted from the document "Data Base for Radioactive Waste Management, Volume 3, Impact Analysis Methodology Report," NUREG/CR-1759.

1. INTRODUCTION AND OVERVIEW

This section presents the basic assumptions for development of the codes. The discussion presented includes the purpose of the analyses; the data base and the general approach adopted in the compartmentalization of the analyses into five separate codes; and an overview of the five codes.

1.1 Purpose

The purpose of the alternatives analyses is to systematically examine the costs and impacts resulting from the management and disposal of LLW under a wide range of viable alternatives. Consideration of the costs and impacts of the various viable alternatives leads to selection of preferred performance objectives and technical criteria.

The impacts considered include long-term safety considerations, short-term safety during operations, long-term socioeconomic commitment, and long- and short-term radiological exposures--occupational exposures as well as exposures to members of the public. In view of past disposal history, long-term performance of the disposal system is stressed in the impacts analyses performed in this environmental impact statement. The long-term performance may be quantified through potential radiological impacts and long-term socioeconomic impacts.

The secondary purpose of the alternatives analyses is to generically assess the impacts of disposal according to the preferred criteria selected in the EIS. These generic results may be utilized as a first estimate of the typical impacts associated with the preferred criteria.

1.2 Summary of Data Bases

The alternatives to be considered result from the variation of parameter values associated with three major aspects of LLW management and disposal. These aspects are disposal technology properties (facility, siting, design, operations, closure, and institutional controls), waste form and packaging properties, and the dose limitation criteria applicable for specific human organs. The first two of these aspects of LLW management and disposal have been examined in Appendices D, E, F, and J, and they have been summarized in Appendix G in the form of indices.

The disposal technology properties have been quantified through thirteen indices, which are summarized in Tables H.1 and H.2 called the disposal technology indices. Each of these disposal technology indices denote a specific calculational procedure in the impact analyses or have a set of disposal properties associated with them. These indices are read into all the computer programs through an array called IRDC. The effects of all the indices and associated information, except for the region index IR, have been incorporated into the internal structure of the computer codes. The data associated with the region index is read into the program from an information file called TAPE1.

The waste form and packaging properties have similarly been quantified through use of waste form behavior indices, which are also summarized in Tables H.1 and H.3. Each index denotes a specific calculational procedure or have certain values of parameters associated with them. Waste form behavior indices have been specified for 36 different waste streams resulting from different waste generation sources, for four different waste spectra resulting from alternative waste processing methodologies which may be adopted by the waste generators or at a central processing facility. The 36 waste streams considered in this EIS are summarized in Table H.4 and the waste spectra are summarized in Table H.5.

There are two comparatively distinct information bases associated with the waste streams: one information base details the basic radiological characteristics of the waste streams, and the other details the behavior of the waste form under different waste spectra. The first information base is stored in an array called BAS, and is also read into the computer programs from TAPE1. The second information base is stored in an array called ISPC and is read into the computer programs through an information file called TAPE2.

Table H.1 Alternatives Analyses Indices

Description	Symbol	Potential Values
<u>Disposal Technology Indices</u>		
Region Index	IR	1 or higher
Design and Operation Indices		
Design	ID	1 or higher
Cover	IC	1, 2, or 3
Stabilization	IX	1, 2, or 3
Emplacement	IE	1, 2, or 3
Site Operational Options		
Segregation	IS	0 or 1
Layering	IL	0 or 1
Grouting	IG	0 or 1
Hot Waste Facility	IH	0 or 1
Postoperational Indices		
Closure Index	IQ	1 or 2
Care Level Index	ICL	1, 2, or 3
Postoperational Period	IPO	Years
Active Institutional Control Period	IIC	Years
<u>Waste Form Behavior Indices</u>		
Flammability Index	I4	0-3
Dispersibility Index	I5	0-3
Leachability Index	I6	1-4
Chemical Content Index	I7	0 or 1
Stability Index	I8	0 or 1
Accessibility Index	I9	1-3

Table H.2 Disposal Technology Indices

Property and Index		Description
Region	- IR	Geographic location of the disposal facility.
Design	- ID	Two options are considered: regular trenches, and the so-called "concrete walled" trenches.
Cover	- IC	Three options on the cover between the waste and the atmosphere are considered: regular, thick, and intruder barrier.
Emplacement	- IE	Three options on the emplacement of the waste are considered: random, stacked, and random combined with decontainerized disposal for unstable wastes.
Stabilization	- IX	Three options on the stabilization program applied to disposal cells, which may contain structurally unstable wastes, are considered: regular, moderate, and extensive.
Layering	- IL	Option on separating and putting selected waste streams (usually with higher external radiation levels) at the bottom of the disposal cell.
Segregation	- IS	Option to segregate and separately dispose of wastes that are combustible/compressible and those that could contain complexing agents.
Grouting	- IG	Option on filling of the interstitial spaces between the wastes with grouting material.
Hot waste facility	- IH	Option on having a special area within the disposal facility with special procedures to handle high activity wastes.
Closure index	- IQ	This index indicates the activities during the closure period (regular or extensive).
Care level index	- ICL	This index indicates the care level anticipated during the active institutional control period (low, moderate, and high).
Postoperational period (years)	- IPO	Duration of the period between the cessation of active disposal and the transfer of the title from the site operator to the site owner.
Institutional control period (years)	- IIC	Duration between transfer of the title to the site owner and the assumed time for loss of institutional controls over the site.

Table H.3 Waste Form Behavior Indices

Parameter and Symbol		Indices
Flammability	(I4)	0 = nonflammable 1 = low flammability (mixture of material with indices of 0 and 2) 2 = burns if heat supplied (does not support burning) 3 = flammable (supports burning)
Dispersibility	(I5)	0 = near zero 1 = slight to moderate 2 = moderate 3 = severe
Leachability	(L)	1 = unsolidified waste form 2 = Type A solidification 3 = Type B solidification 4 = Type C solidification
Chemical content	(I7)	0 = no chelating agents or organic chemicals 1 = chelating agents or organic chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form 1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible 2 = moderately accessible 3 = accessible with difficulty

Table H.4 Waste Groups and Streams

Waste Stream	Symbol
Group I: LWR Process Wastes	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartrides	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
Group II: Trash	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-COTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS* Trash (large facilities)	N-SSTRASH
Industrial SS* Trash (small facilities)	N+SSTRASH
Industrial Low Trash (large facilties)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
Group III: Low Specific Activities Wastes	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV** Waste (large facilities)	I-LIQSCVL
Institutional LSV** Waste (small facilities)	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS* Waste	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
Group IV: Special Wastes	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
High Activity Waste	N-HIGHACT

*SS = Source and special nuclear material.
**LSV = Liquid scintillation vial.

Table H.5 Summary Description of Waste Spectra

Waste Spectrum 1

This spectrum assumes a continuation of past or existing waste management practices. Some of the LWR wastes are solidified; however, no processing is done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be shipped to disposal sites in a dewatered form. LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified with various media designated as solidification scenario A. No special effort is made to compact trash. Institutional waste streams are shipped to disposal sites after they are packaged in currently utilized absorbent materials. Resins from LWR decontamination operations are solidified in a medium with highly improved characteristics (solidification scenario C).

Waste Spectrum 2

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification scenario B). LWR concentrated liquids are additionally reduced in volume, to 50 weight percent solids, through an evaporator crystallizer. In the case of cartridge filters, the solidification agent fills the voids in the packaged waste but does not increase the volume. Liquid scintillation vials are crushed at large facilities and packed in absorbent material. All compactible trash streams are compacted; most at the source of generation and some at the disposal facility. Liquids from medical isotope production facilities are solidified using solidification scenario C procedures.

Waste Spectrum 3

In this spectrum, LWR process wastes are solidified assuming that further improved solidification agents are used (solidification scenario C). LWR concentrated liquids are first evaporated to 50 weight percent solids. All possible incineration of combustible material (except LWR process wastes) is performed; some incineration is done at the source of generation and some at the disposal site. All incineration ash is solidified using solidification scenario C procedures.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All waste amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification scenario C procedures; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All noncompactible wastes are reduced in volume at the disposal site or at a central processing facility using a large hydraulic press. This spectrum represents the maximum volume reduction that can be currently achieved.

The third aspect of the LLW management and disposal to be considered in the alternatives analyses--the dose limitation criteria--has been discussed in Chapters 4 and 5 of this environmental impact statement as well as in Appendix N.

Finally, the last set of basic information utilized in all the computer programs regards the characteristics of the radionuclides considered in the EIS and the pathway dose conversion factors used to determine radiological impacts when radioactivity has reached a location which may be assessed by humans. The 23 radionuclides considered in this EIS are summarized in Table H.6, while the development of and specific values for the pathway dose conversion factors are presented in Sections 1 and 2 of Appendix G. This data is stored in several arrays (see Section 6), and is also read into the computer programs from TAPE1.

A very large number of alternatives result from possible variations in values associated with these three aspects of LLW management and disposal. For example, there are 5,184 possible permutations of only ten of the disposal technology indices, for each region (IR), for each postoperational period (IPO) and for each active institutional control period (IIC). Therefore, the analyses of alternatives must utilize computer programs to rapidly calculate and assess the impacts. Furthermore, several computer programs are needed to examine and assess an isolated portion of the decision base that results from the analyses.

1.3 Overview of Computer Codes

As stated previously, long-term performance of the disposal system is stressed in this environmental impact statement. In the analyses of the radiological impacts, there are three major potential modes of exposure (see Appendix G, Section 2) two of which relate to the longer-term safety consideration: humans inadvertently contacting the waste after disposal (imputs are primarily a function of the concentration of radionuclides in the waste), and the waste entering one of several natural pathways back to biota (impacts are primarily a function of the total activity disposed of at the site).

The first step in the alternatives analyses, therefore, involves a screening of the impacts to potential inadvertent intruders. This is performed through a code called INTRUDE which determines the radiological impacts resulting from potential human inadvertent intrusion into a selected disposal facility location and design containing waste processed through one of the aforementioned waste spectra as a function of time after disposal. The results of this analysis are examined in Chapter 4.

The second step in the alternatives analyses involves determination of long-term radiological and cost impacts including those which may result from potential ground-water migration, and other radiological and nonradiological impacts. These analyses are performed through two codes called GRWATER and OPTIONS. The results of this analysis are examined in Chapter 5.

Attention is principally focused upon long-term radiological impacts of potential inadvertent intrusion into disposed wastes and potential ground-water

Table H.6 Radionuclides Considered in Waste Source Options

Isotopes	Half Life (Years)	Principal Means of Production
H-3	12.3	Fission Li-6 (n, α)
C-14	5730	N-14 (N, p)
Fe-55	2.60	Fe-54 (n, γ)
Co-60	5.26	Co-59 (n, γ)
Ni-59	80,000	Ni-58 (n, γ)
Ni-63	92	Ni-62 (n, γ)
Sr-90	28.1	Fission
Nb-94	20,000	Nb-93 (n, γ)
Tc-99	2.12×10^5	Fission; Mo-98 (n, γ), Mo-99 (β^-)
I-129	1.17×10^7	Fission
Cs-137	30.0	Fission
U-235	7.1×10^8	Natural
U-238	4.51×10^9	Natural
Np-237	2.14×10^6	U-238 (n, 2n), U-237 (β^-)
Pu-238	86.4	Np-237 (n, γ), Np-238 (β^-); daughter Cm-242
Pu-239	24,400	U-238 (n, γ), U-238 (β^-), Np-239 (β^-)
Pu-140	6,580	Multiple n-capture
Pu-241	13.2	Multiple n-capture
Pu-242	2.79×10^5	Multiple n-capture; daughter Am-242
Am-241	458	Daughter Pu-241
Am-243	7950	Multiple n-capture
Cm-243	32	Multiple n-capture
Cm-244	17.6	Multiple n-capture

migration of radionuclides, as well as potential long-term costs to a site owner for surveillance and control of a closed disposal facility. A number of alternatives for waste form and packaging, and disposal facility design and practices may be examined for means to mitigate or reduce these potential long-term radiological and cost impacts. As a byproduct of implementing these alternatives, however, there are short-term costs such as waste processing, transportation, and disposal costs as well as short-term radiological impacts such as occupational exposures during waste handling and population exposures due to waste processing.

The code GRWATER calculates the individual exposures resulting from use of contaminated water drawn from various human access locations such as a well that may become contaminated as a result of potential ground-water migration of radionuclides. These radiological impacts may be examined for several sets of disposal technology indices and a selected waste spectrum. Exposures are calculated as a function of time and may be presented as (1) total exposures from the contribution of all waste streams, (2) total exposures from a particular waste stream or group of waste streams, and (3) exposures from each of the radionuclides considered.

The code OPTIONS calculates waste volume-averaged inadvertent intruder impacts, impacts resulting from exposed waste scenarios, as well as impacts resulting from operational accidents and impacts associated with short-term considerations such as waste processing and transportation impacts, disposal costs, energy use, land use, etc.

In addition to these three codes which consider projected low-level waste characteristics, two codes have been developed to calculate limiting concentrations in waste streams and total inventories in disposal facilities for specific cases. One of these codes is called INVERSI and calculates the limiting concentrations in waste to meet a specific dose criterion for a specific disposal facility design; it may be used for waste classification purposes. The other code is called INVERSW and calculates disposal facility radionuclide inventories (or average concentrations in waste) to meet specific allowable dose criteria for ground-water migration for a specific disposal facility design and environmental characteristics.

All the codes utilized to perform the analyses are presented in Section H.6. The codes have been designed to optimize execution (running) time rather than memory. They have been executed in a CDC-6600 computer in a time sharing mode. They use just two lines of input: an IRDC(12) array which contains the disposal technology indices presented above, and a NOTE(6) array which is a 60 character descriptive title that can be arbitrarily set. The rest of the data is input to the codes through two tapes: TAPE1, which contains most of the generic data (see Section 6) and TAPE2 which contains waste spectrum specific information. A listing of these tapes are also presented in Section 6.

Alteration of the codes for other systems should be relatively easy since they use only standard FORTRAN functions that are commonly used. Output formats and statements, however, should be closely checked, since they can vary significantly from one computer system to the next.

1.4 Waste Classification Test Procedure

Based upon the analysis performed in Chapters 4 and 5, a waste classification test procedure was developed. The test procedure is used in the OPTIONS and GRWATER computer codes to determine radiological, economic, and other impacts from LLW disposal.

In the claculations, the disposal status of each waste stream, denoted by the status index I11, is determined and is used internally in the computer codes. It denotes if any special procedures are required to dispose of the waste stream in a near-surface disposal facility or if the waste is unacceptable for near-surface disposal.

The index, I11, is 1 if the waste is disposable through "regular means." It is 2 if layering of the waste is required, and 3 if the waste is disposed of in a hot waste facility. For disposal by regular means, no special consideration is given to providing barriers against potential inadvertent intruder exposures. Layering of waste streams provides a barrier against an intruder contacting the layered waste streams. Disposal into a hot waste facility provides additional barriers against intrusion. An index value of 0 indicates that the waste is unacceptable for near-surface disposal. The testing procedure utilized in the determination of the disposal status index is presented in Figure H.1.

Each test consists of successively subjecting a given waste stream to the intruder-construction and the intruder-agriculture scenarios after a given period of time, and determining if the calculated radiological impacts in each scenario for each human organ due to all the radionuclides in the waste stream meet given organ-specific dose limitation criteria. Therefore, there are four basic variables in these tests: (1) the waste status (regular or layered or hot waste test), (2) the type of test (standard or modified), (3) the time after the transfer of the site title to site owner at which the test is applied (after the active institutional control period--denoted by IIC years, or after 500 years, or after 1000 years), and (4) the dose limitation criteria which is applied to all the tests. The first three variables are discussed below.

For a given waste stream, first the regular disposal test is applied at IIC years. This regular disposal test may be either a standard or a modified test depending on whether the waste form is stable (I8=1) and the waste streams are being segregated (IS=1) at the disposal site (see Figure H.1). If the waste is found acceptable during the standard test, then it is classified as regular waste. If the waste passes a modified test, it must also pass a regular standard waste test at 500 years before being classified as regular.

If the waste stream fails any of the above three tests, then it is not regular waste. In this case, the layered disposal tests are applied to the waste stream at IIC years if the layering option is available to the disposal technology case being considered--i.e., if IL is equal to unity. The layered test can also be a standard or modified test depending on the values assigned to

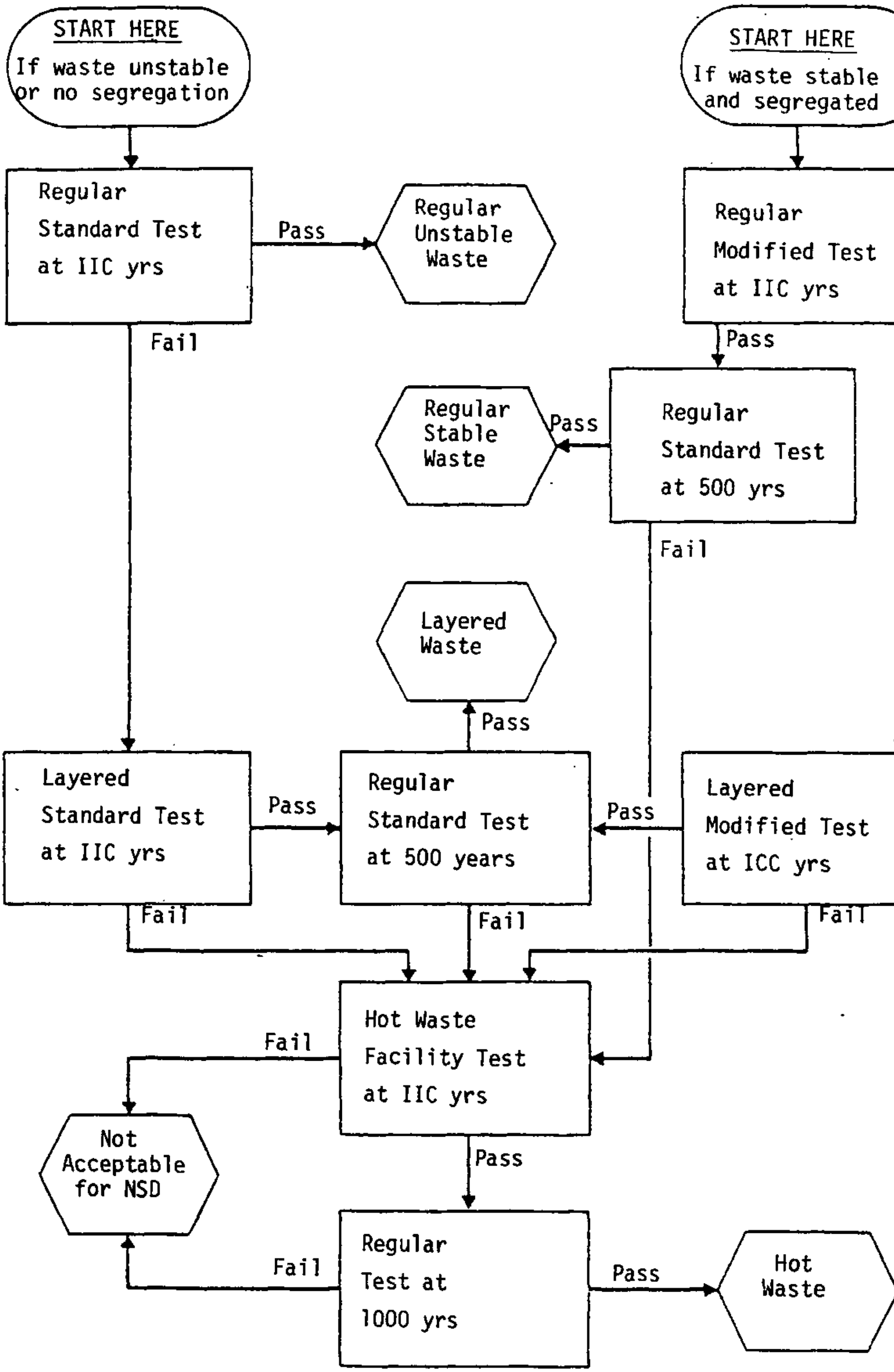


Figure H.1 Waste Classification Test Procedure the waste stability index (I8) and the segregation index (IS). In both of these cases, a waste stream that passes either of the layered tests is tested again in a regular standard waste test at 500 years before being classified as layered waste.

If the layering option is not available or if the waste stream is found not to be acceptable for layered disposal (i.e., it fails one of the above three tests), then hot waste facility disposal is attempted if that option is available to the disposal case technology being considered--i.e., if IH is equal to 1. There are two tests for the hot waste facility option: one is a special hot waste test at IIC years, and the other is a regular standard test at 1000 years. If the waste is found to be unacceptable in any of these options--there may be no option but regular disposal, i.e., IL = 0 and IH = 0--then the waste is considered unacceptable for near-surface disposal for the disposal technology under consideration and for the dose limitation criteria being applied. In this manner the status index I11 is determined and utilized in the total activity scenarios as briefly summarized below and described in Sections G.3.5 and G.3.6 of Appendix G.

If the disposal status of the waste stream is 1 or 2 (regular or layered waste), then no special reduction factors are applied to the ground-water scenarios. However, if the disposal status is 3, then the percolation component of the ground-water scenario is reduced to 25 percent of its minimum value (Section G.3.5). This reduction is due to the special measures adopted in the design of a hot waste facility.

If the disposal status of the waste is 1, then no special reduction factors are applied to the exposed waste scenarios. However, if the disposal status is 2, then the wastes are exempted from the erosion-initiated exposed waste scenarios (they are beneath a minimum of 6 to 7 meters of other material) and only 1 percent of the waste is assumed to contribute to the intruder-initiated exposed waste scenarios (Appendix G, Section G.3.6). For a disposal status of 3, the wastes are exempted from the erosion-initiated exposed waste scenarios and only 0.1 percent of the wastes are assumed to contribute to the intruder-initiated exposed waste scenarios (Appendix G, Section G.3.6).

As described above, there are five distinct classification tests: regular standard, regular modified, layered standard, layered modified, and hot waste facility. These tests are briefly described below.

Regular Standard Test

In this test, no additional reduction factors are applied to either the intruder-construction or intruder-agriculture scenario. This test may be exercised for regular wastes at the end of ICC years, or to wastes that have passed layered waste tests at the end of 500 years, or to wastes that have passed the hot waste facility test at the end of 100 years.

Regular Modified Test

The modified test is applied only at the end of IIC years, and it assumes that the waste stream is stable and segregated from unstable waste streams. Therefore, an inadvertent intruder initiating the intruder-construction scenario will clearly realize that wastes are being intruded into, and will not continue any further (termed intruder-discovery scenario). This results in a substantially reduced contact time for the intruder-construction scenario. The regular standard test uses a contact time of 500 hours, however, in a regular modified test this contact time is reduced to 6 hours (the actual contact time is likely to be no more than half a working day plus 2 hours to account for direct gamma exposure of the intruder through a reduced thickness of cover material). As a consequence of the discovery that wastes are being intruded into, the intruder-agriculture scenario is eliminated in this test.

For the layered standard test, a contact time of 500 hours is assumed. However, for the layered modified test, a contact time of 6 hours is assumed based on the same rationale given for the regular modified test. It should be pointed out that all the waste streams that pass these layered tests undergo a regular standard test at the end of 500 years at which time no credit is assumed for layering.

Hot Waste Facility Test

This test is also applied only at the end of IIC years. The rationale presented above for the layered tests is applicable for the hot waste facility which is designed to confine the wastes regardless of cost or land use considerations. Moreover, it in effect takes unstable wastes, and through disposal design makes them into stable wastes for intrusion purposes. The agriculture scenario is not considered in the hot waste facility test. For the construction scenario a reduction factor of 0.01 is applied to the site design factor for the air uptake component, and a reduction factor of $1/1200^2$ is applied for the direct gamma exposure. Again, it should be pointed out that the waste streams that pass the hot waste facility test are subjected to a regular standard test at the end of 1000 years.

Layered Standard and Modified Tests

In the layered tests, the intruder-agriculture scenario is not applied since the wastes are likely to be disposed of beneath a minimum of 2 meters of cover and 4 to 5 meters of other regular wastes. No reasonable mechanism after only IIC years can be envisioned that would permit the interaction of these wastes with the environment through an intruder-agriculture scenario. For the intruder-construction scenario, different reduction factors are applied to the different uptake pathways: air uptake and the direct gamma exposure pathways.

For the air uptake pathway, only 10 percent of the layered wastes are assumed to be accessible to the intruder. This is a very conservative assumption; it is unlikely that even 1 percent of the area exposed during construction will be the layer of waste underneath 6 to 7 meters of other material. For the direct gamma exposure uptake pathway, the intruder is assumed to be shielded from the layered wastes by at least one meter of soil or equivalent material resulting in a reduction of about 1200 in the radiation intensity.

2. INTRUDE CODE

In determining performance objectives and technical requirements for LLW disposal, an important consideration is the potential for human intrusion into the disposed waste. Such intrusion may act to increase the potential for ground-water migration by increasing the infiltration of precipitation into the waste and it may also bring wastes to the surface where they may potentially be dispersed by wind or water. These actions may result in radiation doses to the surrounding population. However, the largest radiation exposures by far would be to the intruders themselves.

There are four basic scenarios considered for potential intruder exposure:

- the intruder-construction scenario, which involves potential excavation into a closed disposal facility site and construction of a house;
- the intruder-discovery scenario, which is a subset of the intruder-construction scenario and also involves excavation into a closed disposal facility site; however, the time over which excavation activities continue is reduced relative to the intruder-construction scenario;
- the intruder-agriculture scenario, which involves persons potentially living in a house located in contaminated soil and consuming vegetables grown in an onsite garden; and
- the intruder-well scenario, which involves use of contaminated water from an onsite well.

This section and code considers the first three of these scenarios: intruder-construction, intruder-discovery, and intruder-agriculture scenarios. The third scenario, the intruder-well scenario, is considered in the next section on ground-water impacts analyses (the GRWATER code). The potential exposures to the surrounding population as a result of the actions of an intruder, the exposed waste scenarios, are considered in the following section on the OPTIONS codes.

There are three principal means of controlling potential exposures to an intruder: use of institutional controls, use of natural and/or engineered barriers which would make it more difficult for an intruder to contact the waste, and use of less dispersible waste forms. None of these controls can be assumed to be functional forever. However, an important decision to be made at the time of disposal for a given waste stream is whether it requires special considerations with regard to institutional controls, waste form, and natural and/or engineered barriers. INTRUDE performs a screening analyses to determine which waste stream (or streams when mixed and disposed together) requires special consideration.

The code calculates seven human organ doses as a function of time. Also calculated are the ICRP weighted exposure sum over all the organ doses indicative of the total impact of the exposures. The output of the INTRUDE code can be illustrated through an example.

The disposal technology indices (see Tables H.1 and H.2) selected for this example are presented below:

IR = 2	IS = 0
ID = 1	IL = 0
IC = 1	IG = 0
IX = 1	IH = 0
IE = 1	IQ = 1

In addition, the closure period (i.e., IPO) is assumed to be 2 years, and the active institutional control period (i.e., IIC) is varied from 50 years to 2,000 years.

In the analyses, all four waste spectra (see Table H.4) are considered one by one. A number of different analyses may be performed for different groups of waste streams for a given waste spectrum. Four such potential groupings are as follows:

- o Each waste stream separately (36 separate analyses);
- o Waste streams in four macroscopic groups;
- o Waste streams in five major waste generation sources;
- o All the waste streams together.

An example output of the code is presented in Table H.7 for the above reference set of disposal technology indices. The waste spectrum considered is waste spectrum 2, and impacts are presented for the first group of 7 waste streams (LWR process waste streams) shown on Table H.4.

3. GRWATER CODE

This section discusses GRWATER which is a code written to perform an assessment of the impacts from ground-water migration of radionuclides with emphasis on waste form and packaging performance parameters, and site selection and design parameters. After classification of the waste streams into categories in accordance with the test procedure outlined in Section H.1.4 and the dose limitation criteria specified in the code as acceptable, the code computes seven human organ doses as a function of time after closure of the disposal facility for selected biota access locations.

There are three basic scenarios for direct or indirect exposure of humans to radioactivity from potential ground-water migration: an individual-well scenario which envisions drilling of a well either adjacent to a disposal cell or at the site boundary; a population-well scenario which envisions pumping water from a well to satisfy the needs of a small community located between the disposal facility and an open water location receiving ground water passing underneath the site; and a population-surface water scenario which assumes that population exposures result from consumption and utilization of open water that has received discharge from contaminated ground water passing underneath the site.

Table H.7 Example INTRUDE Output (Spectrum 2)

```
APP H
IR = 2  ID = 1  IC = 1  IX = 1
IE = 1  IS = 0  IL = 0  IG = 0
IH = 0  ICL=12  IPD= 2 YEARS  100

GROUP NO = 1
```

YR = 50.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	1.409E+04	1.412E+04	1.412E+04	1.409E+04	1.410E+04	1.410E+04	1.409E+04	2.044E+04
INT-AGRI	1.670E+04	1.675E+04	1.670E+04	1.671E+04	1.669E+04	1.669E+04	1.669E+04	2.422E+04

YR = 100.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	4.347E+03	4.371E+03	4.367E+03	4.345E+03	4.355E+03	4.354E+03	4.344E+03	6.308E+03
INT-AGRI	5.150E+03	5.174E+03	5.155E+03	5.166E+03	5.149E+03	5.148E+03	5.145E+03	7.471E+03

YR = 150.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	1.373E+03	1.395E+03	1.391E+03	1.372E+03	1.381E+03	1.379E+03	1.371E+03	1.996E+03
INT-AGRI	1.626E+03	1.640E+03	1.632E+03	1.645E+03	1.628E+03	1.627E+03	1.624E+03	2.361E+03

YR = 200.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	4.362E+02	4.562E+02	4.526E+02	4.357E+02	4.438E+02	4.418E+02	4.348E+02	6.369E+02
INT-AGRI	5.160E+02	5.264E+02	5.223E+02	5.360E+02	5.186E+02	5.177E+02	5.151E+02	7.507E+02

YR = 300.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	4.790E+01	6.511E+01	6.203E+01	4.769E+01	5.447E+01	5.271E+01	4.675E+01	7.327E+01
INT-AGRI	5.595E+01	6.372E+01	6.154E+01	7.643E+01	5.856E+01	5.777E+01	5.556E+01	8.336E+01

YR = 400.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	9.193E+00	2.445E+01	2.164E+01	9.121E+00	1.494E+01	1.361E+01	8.187E+00	1.672E+01
INT-AGRI	1.018E+01	1.677E+01	1.512E+01	3.076E+01	1.250E+01	1.189E+01	9.876E+00	1.679E+01

YR = 500.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	5.214E+00	1.897E+01	1.634E+01	5.252E+00	1.027E+01	9.460E+00	4.317E+00	1.064E+01
INT-AGRI	5.549E+00	1.137E+01	9.953E+00	2.618E+01	7.598E+00	7.192E+00	5.290E+00	9.932E+00

YR =1000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	4.287E+00	1.361E+01	1.137E+01	4.657E+00	7.189E+00	8.384E+00	3.722E+00	8.403E+00
INT-AGRI	4.705E+00	8.605E+00	7.501E+00	2.547E+01	5.897E+00	6.295E+00	4.579E+00	8.336E+00

YR =2000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INT-CONS	3.859E+00	1.010E+01	8.141E+00	4.459E+00	5.261E+00	7.874E+00	3.522E+00	7.165E+00
INT-AGRI	4.373E+00	7.020E+00	6.056E+00	2.523E+01	4.966E+00	5.931E+00	4.337E+00	7.605E+00

An idealized map of the disposal facility showing the areal relationships of the disposal site and the ground-water access locations was shown in Figure G.6. As indicated in the figure, the transverse (i.e., perpendicular to the ground-water flow direction) dispersion of the contaminants before and after they reach the saturated zone is measured through the geometric reduction factor (r_g). However, the dispersion of the contaminants in the direction of ground-water flow is dependent on the longitudinal (parallel to the ground-water flow direction) extent of the disposal facility.

The longitudinal extent of the disposal facility is taken into account in the analysis by dividing the disposal facility into 10 sectors and applying the point-source equations given in Appendix G to each of the 10 sectors. In this manner, the transverse distribution is taken into account through the factor (r_g), and the longitudinal distribution of the source is numerially integrated.

In this calculation, water starting from each of the sectors has different travel times to the access locations. This travel time is calculated in the computer code through the use of an incremental travel time and Peclet number between the sectors (the DTTM and DTPC arrays), through dividing the source term into 10 equal parts, and placing this source at the center of each sector. The rest of the ground-water migration assumptions have been presented in Appendix G.

The code has several options built into it:

1. it can consider different dose limitation criteria in the initial classification of the wastes into regular, layered, or hot waste facility wastes;

2. it can exclude a waste stream or group of waste streams from the analysis through the use of the NDX(36) array;

3. it can consider a waste stream or group of waste streams packaged in high integrity containers thereby postponing the initiation of the ground-water migration scenario for those streams for a specified period of time;

4. it has the option to perform a time dependent source term calculation, and increase the released source term after an intruder and/or time causes percolation values to increase;

5. it can provide the total exposures from the contribution of all the radionuclides in all the streams, total exposures from all the radionuclides from a particular waste stream or group of streams, or exposures from each of the radionuclides considered in all or some of the waste streams.

A portion of an example output of GRWATER is presented in Table H.8 for the case of waste spectrum 2, and the following disposal facility indices:

IR = 2	ID = 1	IC = 2	IX = 2	IE = 1
IS = 1	IL = 1	IG = 0	IH = 1	IQ = 1
ICL = 2	IPO = 2 years		IIC = 100 years	

Table H.8 Example GRWATER Output (Spectrum 2)

```
APP H
SPECTRUM  2
IR = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2 YEARS  100
VREG = 6.78E+05 VLAY = 0.       VHOT = 0.       VNOT = 1.94E+04

YR =   40.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =   50.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =   60.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  3.536E-03  2.125E-10  3.536E-03  3.536E-03  3.536E-03  3.536E-03  3.536E-03  4.703E-03
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =   70.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  1.111E+00  6.672E-08  1.111E+00  1.111E+00  1.111E+00  1.111E+00  1.111E+00  1.477E+00
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =   80.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  6.543E-01  3.931E-08  6.543E-01  6.543E-01  6.543E-01  6.543E-01  6.543E-01  8.702E-01
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =   90.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  3.726E-01  2.238E-08  3.726E-01  3.726E-01  3.726E-01  3.726E-01  3.726E-01  4.956E-01
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.

YR =  100.    BODY       BONE       LIVER      THYROID    KIDNEY     LUNG       G-I TRACT  ICRP
 BOU-WELL  2.122E-01  1.275E-08  2.122E-01  2.122E-01  2.122E-01  2.122E-01  2.122E-01  2.822E-01
 POP-WELL  0.         0.         0.         0.         0.         0.         0.         0.
 POP-SURF  0.         0.         0.         0.         0.         0.         0.         0.
```

Table H.8 (continued)

	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
YR = 700.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	3.913E-03	1.282E-02	2.996E-03	1.056E+00	3.716E-03	2.567E-03	3.335E-03	3.803E-02
POP-WELL	4.609E-15	2.769E-22	4.609E-15	4.609E-15	4.609E-15	4.609E-15	4.609E-15	6.131E-15
POP-SURF	0.	0.	0.	0.	0.	0.	0.	0.
YR = 800.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.502E-02	6.762E-02	1.400E-02	1.181E+00	1.480E-02	1.353E-02	1.438E-02	6.278E-02
POP-WELL	2.193E-17	1.317E-24	2.193E-17	2.193E-17	2.193E-17	2.193E-17	2.193E-17	2.917E-17
POP-SURF	1.149E-20	6.898E-28	1.149E-20	1.149E-20	1.149E-20	1.149E-20	1.149E-20	1.528E-20
YR = 900.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.587E-02	6.931E-02	1.450E-02	1.577E+00	1.557E-02	1.387E-02	1.500E-02	7.587E-02
POP-WELL	1.065E-19	6.399E-27	1.065E-19	1.065E-19	1.065E-19	1.065E-19	1.065E-19	1.417E-19
POP-SURF	4.003E-22	2.404E-29	4.003E-22	4.003E-22	4.003E-22	4.003E-22	4.003E-22	5.324E-22
YR = 1000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	1.580E-02	6.853E-02	1.438E-02	1.646E+00	1.549E-02	1.371E-02	1.491E-02	7.773E-02
POP-WELL	2.871E-17	4.410E-17	6.240E-17	9.454E-15	7.337E-16	6.014E-18	1.884E-15	4.792E-16
POP-SURF	5.323E-24	3.197E-31	5.323E-24	5.323E-24	5.323E-24	5.323E-24	5.323E-24	7.080E-24
YR = 2000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	3.290E-02	1.390E-01	2.943E-02	4.014E+00	3.214E-02	2.780E-02	3.067E-02	1.789E-01
POP-WELL	4.959E-04	2.075E-04	1.875E-04	3.548E-01	4.339E-04	4.260E-05	3.121E-04	1.122E-02
POP-SURF	3.205E-26	4.901E-26	6.928E-26	1.066E-23	8.141E-25	6.660E-27	2.091E-24	5.369E-25
YR = 4000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	6.181E-02	2.757E-01	5.727E-02	5.265E+00	6.079E-02	5.515E-02	5.882E-02	2.701E-01
POP-WELL	2.655E-03	2.731E-03	1.221E-03	1.647E+00	2.332E-03	5.514E-04	1.709E-03	5.278E-02
POP-SURF	4.889E-05	2.038E-05	1.839E-05	3.506E-02	4.248E-05	4.105E-06	2.997E-05	1.109E-03
YR = 6000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	7.346E-02	3.339E-01	6.892E-02	5.277E+00	7.243E-02	6.680E-02	7.044E-02	2.925E-01
POP-WELL	1.039E-02	4.140E-02	8.955E-03	1.655E+00	1.006E-02	8.286E-03	9.436E-03	6.771E-02
POP-SURF	1.047E-04	4.357E-05	3.927E-05	7.507E-02	8.959E-05	8.780E-06	6.063E-05	2.374E-03
YR = 8000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	6.522E-02	2.927E-01	6.068E-02	5.268E+00	6.418E-02	5.857E-02	6.218E-02	2.766E-01
POP-WELL	1.477E-02	6.329E-02	1.333E-02	1.659E+00	1.444E-02	1.266E-02	1.381E-02	7.615E-02
POP-SURF	1.414E-04	2.275E-04	7.606E-05	7.510E-02	1.263E-04	4.558E-05	9.712E-05	2.445E-03
YR = 10000.	BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
BOU-WELL	5.277E-02	2.305E-01	4.823E-02	5.255E+00	5.172E-02	4.611E-02	4.971E-02	2.526E-01
POP-WELL	1.661E-02	7.249E-02	1.517E-02	1.661E+00	1.627E-02	1.450E-02	1.564E-02	7.969E-02
POP-SURF	6.848E-04	2.943E-03	6.194E-04	7.563E-02	6.695E-04	5.889E-04	6.402E-04	3.493E-03

4. OPTIONS CODE

The previous two codes, INTRUDE and GRWATER, concentrate on the long-term radiological impacts resulting from the disposal of LLW. This section presents a code for calculating all the impact measures other than ground-water impacts.

The calculated results include five major components: (1) the volumes of waste requiring different disposal practices--i.e., the volumes in each disposal status which vary depending on the disposal technology indices and waste form behavior parameters determined by the waste spectrum assumed; (2) disposed waste-volume-averaged inadvertent intruder impacts; (3) radiological impacts resulting from potential exposed waste scenarios; (4) exposures which may result from abnormal operating conditions (accident scenarios); and finally (5) the impact measures applicable to the different phases associated with LLW management and disposal (i.e., waste processing, transportation, disposal) consisting of costs, occupational exposures, population exposures, energy use, and land use. OPTIONS code calculates these five items. All radiological impacts (except occupational exposures and population exposures from waste transportation which are total body exposures) calculated include seven human organs.

The volumes of waste in each disposal status, however, have further been divided within each major category--i.e., regular, layered, and hot waste facility wastes--into four subcategories: stable with no chemical agents (NCH-STAB), stable with chemical agents (CH-STAB), unstable with no chemical agents (NCH-STAB) and unstable with chemical agents (NCH-STAB).

The code has most of the same capabilities in the GRWATER code. For example, it can consider different dose limitation criteria in the initial classification of the wastes, it can exclude streams from the analysis, etc.

A portion of an example output of OPTIONS is presented in Tables H.9 through H.11 for the case considered in the GRWATER code example.

5. INVERSI AND INVERSW CODES

The inverse codes calculate the maximum average concentrations (or inventories) that may be disposed within the radiological guidelines considered (maximum exposure limits) and various disposal technology properties. There are two inverse codes: intruder (INVERSI), and ground water (INVERSW). In each case, the maximum average concentrations for a given set of disposal technology parameters are calculated for 1 million m^3 of waste disposed in the facility.

For these two codes the basic data matrices BAS and ISPC are not utilized. The waste form parameters, however, are input into the calculation through the array ISPC, and the disposal technology indices are input through the IRDC array.

The major option available in the running of these codes is to set dose limitation criteria to different sets of values. In addition, INVERSI code calculates and prints the results of all seven distinct waste classification tests--i.e.,

Table H.9 Example Options Output - 1

```
DISPOSAL TECHNOLOGY INDICES
IW = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2  IIC= 100

REGULAR WASTE :                                  6.756E+05 M**3
     CH=STAB     I=LQSCNVL 3.182E+04
                 I=ABSLIQD 2.546E+03
                 I+ABSLIQD 4.628E+03
                 N=TRITIUM 9.616E+02
                 TOTAL VOLUME  :                 3.995E+04 M**3
     CH=UNSTAB   I+LQSCNVL 4.072E+04
                 I=BIOWAST 6.332E+03
                 I+BIOWAST 8.332E+03
                 N=LOWASTE 1.665E+04
                 TOTAL VOLUME  :                 7.404E+04 M**3
     NCH=STAB    P=IXRESIN 1.578E+04
                 P=CONCLIQ 2.040E+04
                 P=FSLUDGE 1.950E+03
                 P=FCARTRG 6.014E+03
                 B=IXRESIN 3.475E+04
                 B=CONCLIQ 3.774E+04
                 B=FSLUDGE 7.703E+04
                 P=NCTRASH 6.017E+04
                 B=NCTRASH 2.734E+04
                 F=PROCESS 2.159E+04
                 U=PROCESS 7.765E+03
                 N=SSWASTE 1.751E+04
                 L=NFRCOMP 7.975E+02
                 N=HIGHACT 7.204E+02
                 N=TARGETS 3.702E+02
                 TOTAL VOLUME  :                 3.299E+05 M**3
     NCH=UNSTAB  P=COTRASH 5.862E+04
                 B=COTRASH 2.881E+04
                 F=COTRASH 4.344E+04
                 F=NCTRASH 1.152E+04
                 I=COTRASH 1.943E+04
                 I+COTRASH 9.717E+03
                 N=SSTRASH 3.308E+04
                 N+SSTRASH 1.654E+04
                 N=LOTRASH 6.994E+03
                 N+LOTRASH 3.497E+03
                 TOTAL VOLUME  :                 2.317E+05 M**3

LAYERED WASTE :                                  2.871E+03 M**3
     CH=STAB     N=ISOPROD 2.871E+03
                 TOTAL VOLUME  :                 2.871E+03 M**3

NOT ACCEPTABLE:                                  1.938E+04 M**3
                 L=DECONRS 1.933E+04
                 N=SOURCES 5.152E+01
```

Table H.10 Example OPTIONS Output - 2

		BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	G-I TRACT	ICRP
INTRUDER IMPACTS									
	INT-CONS	3.259E+01	3.360E+01	3.266E+01	3.234E+01	3.250E+01	3.253E+01	3.236E+01	4.735E+01
	INT-AGRI	2.151E+01	2.606E+01	2.024E+01	2.019E+01	2.020E+01	2.021E+01	2.031E+01	3.132E+01
	INT-CONS	1.925E+00	6.251E+00	5.404E+00	1.921E+00	3.508E+00	3.745E+00	1.644E+00	3.815E+00
	INT-AGRI	2.205E+00	4.668E+00	3.587E+00	8.307E+00	2.839E+00	2.905E+00	2.120E+00	3.876E+00
	INT-CONS	3.226E-01	3.241E+00	2.536E+00	4.227E-01	1.231E+00	2.097E+00	1.456E-01	1.211E+00
	INT-AGRI	3.725E-01	2.032E+00	1.247E+00	6.926E+00	7.463E-01	1.064E+00	3.350E-01	1.080E+00
EXPOSE/ACC IMPACTS									
	INT-AIR	1.194E+03	2.161E+04	1.233E+04	3.781E+03	7.798E+03	9.787E+03	2.626E+01	6.284E+03
	ERO-AIR	6.111E+00	1.198E+02	7.940E+01	6.451E+01	2.750E+01	1.086E+02	3.549E-01	4.189E+01
	INT-WAT	1.848E-03	5.512E-03	1.433E-03	1.069E-04	5.557E-04	2.366E-04	2.344E-04	2.674E-03
	ERO-WAT	8.866E-02	7.030E-01	1.413E-01	9.939E-01	1.075E-01	5.408E-02	1.612E-01	2.351E-01
	ACC-SNGC	1.460E-01	4.595E-01	2.437E-01	8.174E-02	1.568E-01	9.680E-01	7.052E-02	3.480E-01
	ACC-FIRE	5.894E+00	1.881E+01	9.769E+00	3.185E+00	6.287E+00	2.841E+01	2.491E+00	1.277E+01
	ACC-AVG	3.020E+00	9.635E+00	5.006E+00	1.633E+00	3.222E+00	1.469E+01	1.281E+00	6.559E+00

Table H.11 Example OPTIONS Output - 3

OTHER IMPACTS	WASTE GENERAT	PROCESSING DISPOSAL	TRANSP	DISPOSAL	LT CARE	.100	.090	
COST ($)	5.80E+08	3.63E+07	1.85E+08	1.97E+08	1.81E+07	3.67E+06	0.	1.44E+07
UNIT COST ($/M3)	8.54E+02	5.39E+01	2.72E+02	2.90E+02	2.67E+01	5.42E+00	0.	2.13E+01
POP DOSE (MREM)	0.	0.	5.01E+05	0.				
OCC DOSE (MREM)	3.91E+06	1.25E+05	5.43E+06	2.34E+06				
LAND USE (M**2)	0.	0.	0.	2.36E+05				
ENERGY USE (GAL)	1.73E+07	4.42E+05	1.53E+07	1.22E+06				

regular standard test at IIC years, regular modified test at IIC years, layered standard test at IIC years, layered modified test at IIC years, hot waste facility test at IIC years, regular standard test at 500 years, and regular standard test at 1000 years. INVERSW code also performs two sensitivity analyses: (1) it varies the percolation value associated with the given region index IR by assuming 50 percent of the value, the value given, and twice the value given, and (2) it varies the retardation characteristics of the soils by calculating the limiting concentrations for all five sets of retardation coefficients considered in this work (see Appendix G).

These codes use a modified version of TAPE1 containing the pathway dose conversion factors and the environmental parameters associated with the given region index IR.

6. LISTING OF THE CODES AND DATA FILES

Table H.8 presents symbolic definitions of the data utilized in the analyses which have been presented in the previous chapters. Also given are the computer code definitions of most of the parameters, and some of the assumed values for the analyses.

Almost all the codes use two tapes (some do not need to use all the information contained in these tapes) for input information: TAPE1 contains waste spectrum independent information such as radionuclide concentrations of unprocessed waste, nuclide specific parameters, and environmental parameters; and TAPE2 contains information on the waste spectrum being considered--e.g., volume reduction and increase factors, and waste form behavior indices. In addition, INPUT (query by the code at the terminal the code is being run from) is utilized for reading in the disposal technology indices and descriptive "header" information.

The listing of the codes are presented following Table H.12. These include the following:

Codes	Data files	
INTRUDE	DATA	SPC1
GRWATER	DATAD	SPC2
OPTIONS	NUCS	SPC3
INVERSI		SPC4
INVERSW		

Table H.12 General Data Definitions

CONTROL INTEGERS AND VALUES (Read from Tape 1)

NS: Number of Waste Streams - 36
Individual streams are usually denoted by ISTR.

NNUC: Number of Radionuclides - 23
Individual nuclides are usually denoted by INUC.

FICRP(7): This array, which is located in BAST Common Block and read from Tape 1, contains ICRP body equivalent factors for the seven human organs being considered in the analysis. The values are 1.0, 0.12, 0.06, 0.03, 0.06, 0.12, and 0.06 for total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively.

WASTE STREAM DEPENDENT ARRAYS

BAS(36,32): Basic Data Matrix
Location: BAST Common Block
Read From: Tape 1

This matrix contains most of the waste stream dependent basic information. The first index of this array refers to the 36 waste streams assumed for the analysis. The second index refers to the following:

Index	Description
1	Waste Stream Name - Alphanumeric.
2	(Reserved)
3	When input, it is the untreated volume of the waste stream in m^3 generated between 1980 and 2000 for a region or for the entire country. This may then be replaced with the normalized disposed waste volume in subroutine COMBYN. For waste spectrum 1, the sum of this value over all streams is one million m^3. For other waste spectra it is referenced to spectrum 1.
4	Gross undecayed activity of the untreated waste (Ci/m^3). This value is used only in transportation calculations; it is not modified in the program.
5-27	Radionuclide concentrations of the waste streams decayed to year 2000 for the 23 radionuclides in the stream (Ci/m^3). The concentrations are modified by volume reduction and increase factors (if applicable) and stored on top of the old concentrations in subroutine COMBYN.
28	Transported waste volume in m^3 which is calculated in subroutine COMBYN. Depending on where the waste processing takes place, this value may be different from the disposed waste volume, i.e., BAS(ISTR,3).

Table H.12 (continued)

Index	Description
29-32	Waste processing impacts: costs ($), occupational dose (mrem), energy use (gallons of fuel), and population dose (mrem), respectively, for the waste stream volume given in BAS(ISTR,3). These impacts are calculated in subroutine COMBYN.

ISPC(36.11): Waste Spectrum Matrix
Location: BAST Common Block
Read From: Tape 2

This matrix is read for each waste spectrum and contains all the information that distinguishes waste spectra from each other. The first index of the matrix refers to the waste stream. The second index refers to the following:

Index	Description
1	Waste Packaging Index, which is used in the transportation calculations, and is composed of two digits representing packaging characteristics and the gamma emission characteristics of waste.
2	Volume Reduction Factor multiplied by 100 (to make it an integer).
3	Volume Increase Factor similarly multiplied by 100.
4	Flammability Index - I4
5	Dispersibility Index - I5
6	Leachability Index - I6
7	Chemical Content Index - I7
8	Stability Index - I8
9	Accessibility Index - I9
10	Overall Waste Processing Index (I10) (see Section 5 of Appendix G) which is composed of four processing indices (digits) that are unscrambled and utilized in subroutine COMBYN to calculate BAS(ISTR,29) through BAS(ISTR,32).
11	Waste Disposal Status Index (I11) (see Section H.1.4) which is computed in subroutine RCLAIM.

RADIONUCLIDE DEPENDENT ARRAYS

DCF(23,7,8): Pathway Dose Conversion Factor Matrix
Location: BAST Common Block
Read From: Tape 1

This matrix contains the multiple pathway dose conversion factors discussed in Section 2.4 of Appendix G. DCF(I,J,K) is the pathway dose conversion factor

Table H.12 (continued)

for the radionuclide (I), human organ (J), and pathway (K). Human organs considered (as given for the FICRP array) are total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively. Pathways considered are those resulting from the following release scenarios: accident, construction (air uptake pathway), agriculture (air uptake pathway), agriculture (food (soil) uptake pathway), direct-gamma (volume) exposure), well water, open water, and air (see Section 2.4 of Appendix G). This matrix is not modified by the code.

NUC(23): Radionuclide Names
Location: NUCS Common Block
Read From: Tape 1

This array contains the alphanumeric names of the radionuclides considered in the analysis: H-3, C-14, FE-55, NI-59, CO-60, NI-63, SR-90, NB-94, TC-99, I-129, CS-135, CS-137, U-235, U-238, NP-237, PU-238, PU-239/240, PU-241, PU-242, AM-241, AM-243, CM-243, CM-244.

AL(23): Decay Constants
Location: NUCS Common Block
Read From: Tape 1

This array contains the decay constants of the 23 selected radionuclides in units of $year^{-1}$.

FMF(23): Leachate Partition Ratios
Location: NUCS Common Block
Read From: Tape 1

This array contains the radionuclide dependent partition ratios between the radionuclide concentrations in the trench leachate and in the unsolidified waste (see Appendix G).

RET(23,5): Retardation Coefficients
Location: NUCS Common Block
Read From: Tape 1

This array contains the retardation coefficients of the radionuclides for five different soil conditions (see Appendix G). Only RET(I,1) and RET(I,4) are read in from Tape 1, the rest of the coefficients are calculated from RET(I,1) and RET(I,4) and stored in subroutine COMBYN.

ENVIRONMENT DEPENDENT ARRAYS

Most of the codes utilized provide for six different disposal environments, each of which is denoted by a specific value of IR in the discussion below. The first four cases correspond to the regional characteristics outlined in Appendix J: northeast, southeast, midwest, and southwest. For most of the analysis only the second set of environmental parameters (IR=2), which represen

Table H.12 (continued)

the reference disposal facility environment, are utilized. The fifth and sixth sets of environmental parameters (IR=5 and IR=6) are variations of the reference facility environment and are utilized for the ground-water migration analyses.

FSC(6): Construction Dust Mobilization Factor
Location: DTIS Common Block
Read From: Tape 1

This array (denoting f_s-construction) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions and soil particle size distribution and annual average wind speed, for the air uptake pathway of the intruder-construction scenario.

FSA(6): Agriculture Dust Mobilization Factor
Location: DTIS Common Block
Read From: Tape 1

This array (denoting f_s-agriculture) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions and soil particle size distribution and annual average wind speed, for the air uptake pathway of the intruder-agriculture scenario.

PRC(6,2): Percolation Matrix
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the potential infiltration into the disposal cell modified by the anticipated waste-water contact time given in units of meters for two different conditions: PRC(IR,1) is the no special cover condition, and PRC(IR,2) is the thick cover condition. These percolation values are given in Appendix J.

QFC(6,3): Dilution Factors
Location: DTIS Common Block
Read From: Tape 1

This array contains the dilution factors (Q) in units of (m^3/year) for the three ground-water discharge locations: boundary-well, population-well, and population-surface water discharge locations.

TTM(6,3): Ground-water Travel Time Matrix
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the ground-water travel times in years (t_w) between the sector of the disposal site (see Section 3.6 of Appendix G) closest to the discharge locations and the three ground-water discharge locations mentioned above in QFC(6,3).

Table H.12 (continued)

TPC(6,3): Peclet Number Matrix
Location: DTIS Common Block
Read From: Tape 1

This array contains the dimensionless Peclet Numbers (P) for the ground-water travel times given by the above matrix TTM(6,3).

RGG(6,3): Geometric Migration Reduction Factor
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the geometric reduction factor (r_g) resulting from the transverse relationship of the discharge location and the disposal facility for the three ground-water discharge locations considered in the analysis. These values are assumed to be unity.

POP(6,3): Exposed Waste Site Selection Factors
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the exposed waste site selection factors (f_s): POP(IR,1) and POP(IR,2), in units of person-m^3/year, correspond to the factors for exposed waste-intruder-air and exposed waste-erosion-air scenarios, respectively; and POP(IR,3) corresponds to the exposed waste-surface water (intruder and erosion) scenarios.

DTTM(6): Incremental Travel Times
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the incremental travel times between the sectors of the disposal facility in units of years (see Section 3.6 of Appendix G).

DTPC(6): Incremental Peclet Numbers
Location: DTIS Common Block
Read From: Tape 1

This matrix contains the incremental Peclet numbers between the sectors of the disposal facility (see Section 3.6 of Appendix G).

TPO(6,2): Atmospheric Dispersion Factor Array
Location: DTIS Common Block
Read From: Tape 1

This array contains the atmospheric dispersion factors utilized in the accident scenarios for the disposal facility site location. These factors have units of person-year/m^3 and are the atmospheric (X/Q) factors for a given radial distance multiplied by the population at that distance summed over all distances. TPO(IR,1) is for the accident-fire scenario, and TPO(IR,2) is for the single-container accident scenario.

Table H.12 (continued)

NRET(6):	Retardation Status Array
Location:	DTIS Common Block
Read From:	Tape 1

The values in this array indicate the condition of the soils in the vicinity of the disposal site with regard to the retardation of radionuclides. It determines which RET(23,5) will be used in the ground-water migration analysis, i.e., RET(23,NRET(IR)) is used.

Listing for INTRUDE Computer Code

```
      PROGRAM  INTRUDE (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C       FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
C     TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
C     INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
C     TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE RCLAIM.
C     TAPE4 CONTAINS MAIN PROGRAM OUTPUT (INTRUDER IMPACTS).
C
      COMMON/PAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),TPC(6,3),
+           RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DZD(7,2),DZ(7,2,9)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C
      DIMENSION NOTE(6),TYM(9),DES(2),IGRP(36),DEC(23,2)
      DATA NTYM/9/,TYM/50.,100.,150.,200.,300.,400.,500.,1.E3,2.E3/,
C          NGNX/36/,IGRP/1,2,3,4,5,6,7,8,9,10,11,12,13,14,
C                          15,16,17,18,19,20,21,22,23,24,25,
C                          26,27,28,29,30,31,32,33,34,35,36/
C          NGNX/4/,IGRP/7*1,12*2,10*3,7*4/
C          NGNX/5/,IGRP/11*1,2,2,3,3,4*4,2,2,6*3,4,4,7*5/
+          NGNX/1/,IGRP/36*1/
      DATA DES/10H REC-CONS ,10H REC-AGRI /,DEC/.9,.75,6*2.5E-3,
+     2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
C
C     THE ABOVE MATRICES AND ARRAYS ARE:
C     NOTE(6)   : HEADER LABEL FOR OUTPUT IDENTIFICATION.
C     TYM(9)    : NINE TIME STEPS AT WHICH INTRUDER IMPACTS
C                 ARE CALCULUATED.
C     DES(2)    : DESCRIPTION OF INTRUDER PATHWAYS.
C     IGRP(36)  : ARRAY USED TO DEFINE GROUPING OF WASTE STREAMS.
C     DEC(23,2) : DECON FACTORS FOR INCINERATOR AND CALCINER.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 10 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
   10 READ(2,103)(ISPC(I,J),J=1,10)
      DO 20 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 15 K=1,8
   15 READ(1,106)(DCF(I,J,K),J=1,7)
   20 CONTINUE
C
C     INPUT ENVIRONMENTAL PARAMETERS
C
      DO 25 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(OFC(I,J),J=1,3),
+                 (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+                 (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+                 DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   25 CONTINUE
```

<u>Listing for INTRUDE Computer Code</u> (continued)

```
 101 FORMAT(2I5,7F5.2)
 102 FORMAT(A10,2F10.3/10X,6F10.3/10X,6F10.3/10X,6F10.3/10X,6F10.3)
 103 FORMAT(10X,10I5)
 104 FORMAT(A10,4E10.3)
 105 FORMAT(10X,7E10.3/10X,6F10.3/10X,6F10.3,I5/10X,4F10.3)
 106 FORMAT(10X,7F10.3)
C
     DO 35 ISTR=1,NSTR
     A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
     A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
     DO 30 I=5,27
  30 BAS(ISTR,I)=BAS(ISTR,I)*A1
     J=ISPC(ISTR,10)
     IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
     IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 35
     IF(IP.LT.5)GO TO 35
     J=1 $ IF(IP.GT.5)J=2
     BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
     BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
  35 CONTINUE
C
C    NEXT LINE READS IN - THRU INPUT - THE 12 DISPOSAL
C    TECHNOLOGY INDICES AND HEADER INFORMATION.
C
     READ,IRDC $ READ 1002,NOTE $ WRITE(4,1003) NOTE,IRDC
     DO 70 IGNX=1,NGNX
     NX=0 $ VDIS=0. $ CALL ZERO(DZ,126)
C
C    DO 70 INTERPRETS IGRP(GROUPING) ARRAY
C    DO 50 IS THE MAIN LOOP IN CALCULATING INTRUDER IMPACTS
C    DO 45 LOOP DISTINGUISHES BETWEEN THE TIME STEPS
C
     DO 50 ISTR=1,NSTR
     IF(IGNX.NE.IGRP(ISTR))GO TO 50
     DO 45 ITYM=1,NTYM
     IRDC(12)=TYM(ITYM)+0.1 $ CALL RCLAIM(ISTR,NNUC)
     DO 40 I=1,7
     DO 40 J=1,2
  40 DZ(I,J,ITYM)=DZ(I,J,ITYM)+BAS(ISTR,3)*DZD(I,J)
  45 CONTINUE
     NX=1 $ VDIS=VDIS+BAS(ISTR,3)
  50 CONTINUE
     IF(NX.EQ.0)GO TO 70
     DO 55 I=1,NTYM
     DO 55 J=1,7
     DO 55 K=1,2
  55 DZ(J,K,I)=DZ(J,K,I)/VDIS
     IF(NGNX.EQ.36)WRITE(4,1004) BAS(IGNX,1)
     IF(NGNX.NE.36)WRITE(4,1005) IGNX
     DO 65 I=1,NTYM
     WRITE(4,1006) TYM(I)
     DO 65 K=1,2
     A1=0.
     DO 60 J=1,7
  60 A1=A1+DZ(J,K,I)*FICPP(J)
  65 WRITE(4,1007) DES(K),(DZ(J,K,I),J=1,7),A1
  70 CONTINUE
```

Listing for INTRUDE Computer Code (continued)

```
C
 1001 FORMAT(12I3)
 1002 FORMAT(6A10)
 1003 FORMAT(1H1/2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                           *IE =*I2*  IS =*I2*  IL =*I2*  I8 =*I2/2X
+                           *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
 1004 FORMAT(//2X,A10)
 1005 FORMAT(//2X*GROUP NO =*I2)
 1006 FORMAT(/2X*YR =*F5.0*    BODY       BONE       LIVER*
+     *    THYROID    KIDNEY    LUNG    G-I TRACT   ICRP*)
 1007 FORMAT(2X,A10,8E10.3)
      STOP $ END
C
C
      SUBROUTINE PCLAIM(ISTR,NNUC)
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,I8,IH,ICL,IPO,IIC
+           /DTIS/FSC(6),FSA(6)/IMPS/DZ(7,2)
      DIMENSION EMP(3),DMY(7,5)
      DATA EMP/.5,.75,.5/
C
C     EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
C     DMY(7,5)  : MATRIX TO HOLD 5 SUB-PATHWAYS WHICH WILL LATER
C                 BE ADDED TOGETHER TO DEFINE CONSTRUCTION AND%@
C                 AGRICULTURE PATHWAYS.
C
   10 I5=ISPC(ISTR,5) $ I7=ISPC(ISTR,7) $ I9=ISPC(ISTR,9)
      I6=ISPC(ISTR,6) $ FOES=EMP(IE)*(1.-0.9*I8)
      I8=ISPC(ISTR,8)
      A8=1. $ IF(I6.EQ.2.OR.I6.EQ.3)A8=0.8
      IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
C
C     GDEL DEFINES YEAR OF SCENARIO INITIATION
C
      GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      IF(I9.EQ.3) A8=A8*10.
      A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I12=1
      IF(IL.EQ.0.AND.IS.EQ.1.AND.I8.EQ.1) I12=2
      IF(IL.EQ.1.AND.IS.EQ.0) I12=3
      IF(IL.EQ.1.AND.IS.EQ.1.AND.I8.EQ.1) I12=4
      IF(IH.EQ.1.OR.ID.EQ.2) I12=5
      GO TO (11,12,13,14,15),I12
   11 A4C=1. $ A4A=1. $ A8C=A8 $ A8A=A8 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A8 $ A8A=0. $ GO TO 20
   13 A4C=0.1 $ A4A=0. $ A8C=A8/1200. $ A8A=0. $ GO TO 20
   14 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A8/1200. $ A8A=0. $ GO TO 20
   15 A4C=0.01 $ A4A=0. $ A8C=0.1*A8/1.44E+6 $ A8A=0.
      IF(I8.EQ.0) A8C=A8C*0.1
   20 CONTINUE
      CALL ZERO(DZ,14) $ WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR
  101 FORMAT(/2X,A10,E10.3,I5)
C
```

Listing for INTRUDE Computer Code (continued)

```
C     MAIN LOOP IN CALCULATING DOSES FROM ALL NUCLIDES FOR
C     SEVEN ORGANS.
C
      DO 40 INUC=1,NNUC
      A1=A9*FDES*FXM(AL(INUC)*GDEL)*BAS(ISTR,INUC+4)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      DMY(I,1)=A1*0.057*A2*A8C $ DMY(I,3)=A1*0.27*A2*0.25*A8A
      DMY(I,2)=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      DMY(I,4)=A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)*0.25
      DMY(I,5)=0.25*0.5*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
C     DMY(I,2)=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C     DMY(I,4)=A1*A4A*FSA(IR)*DCF(INUC,I,3)*0.25
C     DMY(I,5)=0.25*0.5*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
      DZ(I,1)=DZ(I,1)+DMY(I,1)+DMY(I,2)
      DZ(I,2)=DZ(I,2)+DMY(I,3)+DMY(I,4)+DMY(I,5)
   30 CONTINUE
      IF(ISTR.LT.30)GO TO 40
C     WRITE(3,102) NUC(INUC),((DMY(I,J),I=1,7),J=1,5)
  102 FORMAT(2X,A10,7E9.2/(12X,7E9.2))
   40 CONTINUE
      RETURN $ END
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
      FUNCTION FXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      FXM=A2
      RETURN $ END
```

Listing for GRWATER Computer Code

```
      PROGRAM GRWATER(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C       FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
C     TAPE2 CONTAINS THE SPECTRAL (ISPC) FILE.
C     INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
C     TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE GWATER.
C     TAPE4 CONTAINS THE MAIN PROGRAM OUTPUT (GROUNDWATER IMPACTS).
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+           RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DZD(23,18,21)/DHIC/IHIC(36),THIC
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS DISPOSAL TECHNOLGY INDICES.
C     IMPS BLOCK  - DZD(23,18,21) - WILL CONTAIN RESULTS OF GWATER
C     - DOSES FOR 23 NUCLIDES, 18 TIME STEPS, 7 ORGAN FOR 3 LOCATIONS.
C     DHIC BLOCK CONCERNS THE USE OF HIGH INTEGRITY CONTAINERS:
C     IHIC INDICATES WHICH STREAMS USE HIGH INTEGRITY CONTAINERS
C     AND THIC IS TIME ATTRIBUTE ASSOCIATED WITH CONTAINER.
C
      DIMENSION TIMP(6),TYM(18),DES(3),DZ(7,3,18),NDX(36)
      DATA NDX/36*1/
      DATA IHIC/36*0/,THIC/100./
      DATA TYM/40.,50.,60.,100.,200.,300.,400.,500.,600.,700.,
+     800.,900.,1000.,2000.,4000.,6000.,8000.,10000./,NTYM/18/
      DATA DES/10H REC-WELL ,10H POP-WELL ,10H POP-SURF /
C
C        NDX(36)      : INDEX TO INCLUDE OR EXCLUDE PARTICULAR
C                       STREAMS IN ANAYSIS (1=INCLUDE, 0=EXCLUDE).
C        TYM(18)      : 18 TIME STEPS TO BE CONSIDERED IN GROUNDWATER
C                       ANALYSIS.
C        DES(3)       : DESCRIPTION OF 3 PATHWAYS OF CONCERN.
C        DZ(7,3,18)   : DOSES SUMMED OVER ALL NUCLIDES.
C
      READ,IRDC $ READ 1002,TIMP $ WRITE(4,1003) TIMP,IRDC
      CALL COMBYN(NSTR,NNUC)
      VNOT=0. $ VREG=0. $ VLAY=0. $ VHOT=0.
C
C     LOOP 30 CLASSIFIES WASTE STREAMS AND ACCUMULATES THEIR
C     VOLUME AS NOT ACCEPTABLE, REGULAR, LAYERED, OR HOT.
C
      DO 30 ISTR=1,NSTR
      IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
      IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD)
      IF(NDX(ISTR).NE.1)ISPC(ISTR,11)=0
      II=ISPC(ISTR,11)+1 $ GO TO(10,15,20,25),II
   10 VNOT=VNOT+BAS(ISTR,3) $ GO TO 30
   15 VREG=VREG+BAS(ISTR,3) $ GO TO 30
   20 VLAY=VLAY+BAS(ISTR,3) $ GO TO 30
   25 VHOT=VHOT+BAS(ISTR,3)
   30 CONTINUE
      WRITE(4,1004) VREG,VLAY,VHOT,VNOT
C
```

<u>Listing for GRWATER Computer Code</u> (continued)

```
      CALL GWATER(NSTR,NNUC,NTYM,TYM) $ CALL ZERO(DZ,378)
C
C     LOOP 40 SUMS DOSES OVER ALL NUCLIDES
C
      DO 40 ITYM=1,NTYM
      DO 40 K=1,3
      KK=(K-1)*7
      DO 40 J=1,7
      DO 40 INUC=1,NNUC
   40 DZ(J,K,ITYM)=DZ(J,K,ITYM)+DZD(INUC,ITYM,KK+J)
C
C     LOOP 70 OUTPUTS GROUNDWATER DOSES FOR 7 ORGANS, 3 PATHWAYS,
C     AND 18 TIMES.
C
      DO 70 ITYM=1,NTYM
      TYMD=TYM(ITYM) $ WRITE(4,1005) TYMD
      DO 60 K=1,3
      A1=0.
      DO 50 J=1,7
   50 A1=A1+DZ(J,K,ITYM)*FICRP(J)
   60 WRITE(4,1006) DES(K),(DZ(J,K,ITYM),J=1,7),A1
   70 CONTINUE
C
C     LOOP 80 OUTPUTS DOSES FOR EACH TIME CONSIDERED FOR EACH NUCLIDE
C
      DO 80 INUC=1,12
      WRITE(4,1007) NUC(INUC)
      DO 80 ITYM=1,NTYM
      DO 80 K=1,3
      KK=(K-1)*7
   80 WRITE(4,1008) TYM(ITYM),DES(K),(DZD(INUC,ITYM,KK+J),J=1,7)
C
 1001 FORMAT(12I3)
 1002 FORMAT(6A10)
 1003 FORMAT(2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
                           *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
                           *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
 1004 FORMAT(2X*VREG =*E9.2* VLAY =*E9.2* VHOT =*E9.2* VNOT =*E9.2)
 1005 FORMAT(/2X*YR =*F5.0*     BODY       BONE       LIVER*
          *    THYROID     KIDNEY     LUNG     G-I TRACT    ICRP*)
 1006 FORMAT(2X,A10,8F10.3)
 1007 FORMAT(/2X,A10,10X*BODY       BONE       LIVER*
          *    THYROID     KIDNEY     LUNG     G-I TRACT*)
 1008 FORMAT(2X,F6.0,2X,A10,7F10.3)
      STOP $ END
C
C
      SUBROUTINE COMBYN(NSTR,NNUC)
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
             /NUCS/NUC(23),AL(23),EMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
             PPC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6)
             DTPC(6),TPO(6,2),NRET(6)
      DIMENSION DEC(23,2)
      DATA DEC/.9,.75,6*2.5E-3,2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,
      2*1.E-4,13*2.5E-5/
```

Listing for GRWATER Computer Code (continued)

```
      READ(1,101)NSTR,NNUC,FICRP
      DO 70 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
      READ(2,103)(ISPC(I,J),J=1,10)
   70 CONTINUE
      DO 80 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 75 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   75 CONTINUE
   80 CONTINUE
      DO 90 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
     +(TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3),
     +NRET(I),DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   90 CONTINUE
  101 FORMAT(2I5,7F5.2)
  102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
  103 FORMAT(10X,10I5)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6F10.3,I5/10X,4F10.3)
  106 FORMAT(10X,7E10.3)
      DO 50 ISTR=1,NSTR
      A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
      A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
      DO 20 I=5,27
   20 BAS(ISTR,I)=BAS(ISTR,I)*A1
      J=ISPC(ISTR,10)
      IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
      IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 50
      IF(IP.LT.5)GO TO 50
      J=1 $ IF(IP.GT.5)J=2
      BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
      BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
   50 CONTINUE
      DO 60 INUC=1,NNUC
      A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
      RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
   60 RET(INUC,2)=RET(INUC,1)*A1
      RETURN $ END
C
C
      SUBROUTINE RCLAIM(ISTR,NNUC,IMOD)
C
C     THIS SUBROUTINE IS USED TO CLASSIFY EACH WASTE STREAM AS:
C         (1) NOT ACCEPTABLE, (2) REGULAR,
C         (3) LAYERED, OR (4) HOT
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
     +      /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
     +      /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,ITC
     +      /DTIS/FSC(6),FSA(6)/IMPS/D7(7,2)/DHIC/IHIC(36),THIC
C
C     D7(7,2) : INTRUDER DOSES USED IN CLASSIFICATION TESTS
C
```

Listing for GRWATER Computer Code (continued)

```
      DIMENSION EMP(5),DLC(7)
      DATA EMP/.5,.75,.5,.5,.75/,DLC/500.,500.,1500.,3000.,3*1500./
C
C     EMP(5) : VOLUME EMPLACEMENT EFFICIENCIES
C     DLC(7) : DOSE LIMITING CRITERIA FOR 7 ORGANS
C
      I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
      I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
      IF(THIC(ISTR).GT.0) I8=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      IF(I7.EQ.1.OR.I5.EQ.0) I6=I6-1
      EDES=EMP(IE)*(1.-.9*IG)
      IF(I9.EQ.3) A7=A7*10.
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
      I3=1 $ IF(I5.EQ.1.AND.I8.EQ.1)I3=2
      IF(ID.EQ.2)I3=2
C
C     TESTING ROUTINE FOR CLASSIFING WASTE, BASED ON INTRUDER
C     CONSTRUCTION AND AGRICULTURE PATHWAYS.
C
   10 GDEL=IPO+TIC $ IF(IC.EQ.3) GDEL=IPO+500.
      CALL ZERO(D7,14) $ GO TO (11,12,13,14,15,16,17,18),I3
   11 A4C=1. $ A4A=1. $ ABC=A7 $ ABA=A7 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ ABC=0.012*A7 $ ABA=0. $ GO TO 20
   13 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ ABC=A7 $ ABA=A7 $ GO TO 20
   14 A4C=0.1 $ A4A=0. $ ABC=A7/1200. $ ABA=0. $ GO TO 20
   15 A4C=0.0012 $ A4A=0. $ ABC=0.0012*A7/1200. $ ABA=0. $ GO TO 20
   16 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ ABC=A7 $ ABA=A7 $ GO TO 20
   17 ABC=0.1*A7/1.44E6 $ IF(IG.EQ.0)ABC=ABC*0.1
      A4C=0.01 $ A4A=0. $ ABA=0. $ GO TO 20
   18 GDEL=IPO+1000. $ ABC=A7 $ IF(IG.EQ.0)ABC=0.1*A7
      A4C=1. $ A4A=1. $ ABA=ABC
C
C     MAIN LOOP FOR CALCULATING DOSES
C
   20 DO 40 INUC=1,NNUC
      A1=A9*EDES*EXM(AL(INUC)*GDEL)*RAS(ISTR,INUC+4)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*ESC(IR)*DCF(INUC,I,2)
      B2=A1*ABC*A2*0.057
      B3=0.25*A1*A4A*A5*ESA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*EME(INUC)*DCF(INUC,I,4)
C     B1=A1*A4C*ESC(IR)*DCF(INUC,I,2)
C     B3=0.25*A1*A4A*ESA(IR)*DCF(INUC,I,3)
C     B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*EME(INUC)
      B5=0.25*A1*ABA*A2*0.27
      D7(I,1)=D7(I,1)+B1+B2
   30 D7(I,2)=D7(I,2)+B3+B4+B5
   40 CONTINUE
C
```

<u>Listing for GRWATER Computer Code</u> (continued)

```
      TEST DOSES AGAINST DLC

      DO 50 IORG=1,7
      DO 50 IPTH=1,2
      IF(DZ(IORG,IPTH).GT.DLC(IORG)) GO TO 60
   50 CONTINUE
      GO TO (51,52,51,53,53,54,55,56),I3
   51 ISPC(ISTR,11)=1 $ RETURN
   52 I3=3 $ GO TO 10
   53 I3=6 $ GO TO 10
   54 ISPC(ISTR,11)=2 $ RETURN
   55 I3=8 $ GO TO 10
   56 ISPC(ISTR,11)=3 $ RETURN
   60 GO TO (61,62,63,63,63,63,70,70),I3
   61 IF(IL.EQ.0)GO TO 63
      I3=4 $ GO TO 10
   62 IF(IL.EQ.0)GO TO 63
      I3=5 $ GO TO 10
   63 IF(IH.EQ.0)GO TO 70
      I3=7 $ GO TO 10
   70 ISPC(ISTR,11)=0

      ISPC(ISTR,11) CONTAINS WASTE CLASSIFICATION INDEX
      RETURN $ END

      FUNCTION ERFS(A1,A2)
      A3=0.5*SQRT(A2/A1)
      A4=A3*(1.-A1) $ A5=A3*(1.+A1)
      IF(A4.GT.0)GO TO 10
      ERFS=2.+EXM(A4*A4)*(POLY(A5)-POLY(-A4)) $ RETURN
   10 ERFS=EXM(A4*A4)*(POLY(A4)+POLY(A5))
      RETURN $ END


      FUNCTION POLY(X1)
      DATA A1,A2,A3,A4,A5,P/.254829592,-.284496736,1.421413741,
                           -1.453152027,1.061405429,.3275911/
      T1=1./(1.+P*X1)
      POLY=T1*(A1+T1*(A2+T1*(A3+T1*(A4+T1*A5))))
      RETURN $ END
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END


      SUBROUTINE GWATER(NSTR,NNUC,NTYM,TYMD)
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
             /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
             /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
             /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
              TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
             /IMPS/DZ(23,18,21)/DHIC/IHIC(36),THIC
      DIMENSION EMP(5),EFF(2),SEFF(2),DMY(3,20),TYMD(18),RES(18,3)
      DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/,NOPT/1/
      TVOL=0. $ GINS=IPO+IIC $ NSEC=10 $ CALL ZERO(DZ,8694)
```

Listing for GRWATER Computer Code (continued)

```
C
C     NEXT SECTION DETERMINES PERCOLATION VALUE AND
C     LOWER LIMIT FOR THE DILUTION FACTOR
C
      PRC1=PRC(IR,1) $ PRC2=PRC(IR,2)
      IF(IG.EQ.1.OR.ID.EQ.2) GO TO 5
      IF(IE.GT.3) PRC1=PRC(IR,1)/10.
      IF(IE.GT.3) PRC2=PRC(IR,2)/10.
    5 CONTINUE
      IF(IC.EQ.1)PRCD=PRC1
      IF(IC.GT.1)PRCD=PRC2
      IF(IX.EQ.1)PRCD=4.*PRC1
      IF(IC.EQ.1.AND.IX.EQ.2) PRCD=2.25*PRC1
      IF(IC.EQ.2.AND.IX.EQ.2) PRCD=4.0*PRC2
      TVOL=352000.*SQRT(PRC(IR,1)*27.8)
      IF(TVOL.LT.7700.) TVOL=7700.
C
C     MAIN LOOP OF GROUNDWATER PATHWAY EQUATION
C           ***********************************
C           SOME OF THE MAIN VARIABLE NAMES ARE:
C           PERC  : SOURCE TERMS
C           PER2
C           FMF   : RADIONUCLIDE PARTITION RATIOS
C           QFC   : DILUTION FACTOR
C           TDUR  : DURATION TIME OF RADIONUCLIDE
C           RES   : MIGRATION REDUCTION FACTOR
C           RGF   : GEOMETRICAL REDUCTION FACTOR
C           ************************************
C
      DO 90 ISTR=1,NSTR
      I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 90
      WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR,I11
      I6=ISPC(ISTR,6) $ VUR=0.9/(EMP(IE)*FFF(ID))
      I7=ISPC(ISTR,7) $ IF(I11.EQ.3)VUR=0.19
      I8=ISPC(ISTR,8) $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
      I9=ISPC(ISTR,9) $ GDFL=0. $ IF(IHIC(ISTR).EQ.1)GDFL=THIC
      IF(IHIC(ISTR).GT.0) I8=1
      PERC=PRCD $ IF(I8.NE.1.OR.IS.NE.1)GO TO 10
      IF(IC.EQ.1)PERC=PRC1
      IF(IC.GT.1)PERC=PRC2
   10 IF(I11.EQ.3.OR.ID.EQ.2)PERC=PRC2/16.
      PERC=PERC*(1.0-0.9*IG) $ PER2=3.6*PERC+0.1*PRC1
      IF(ID.EQ.2)PER2=0.9*PERC+0.1*PRC2
      NX=0 $ IF(PERC.LT.PRC1)NX=1
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I1=NRET(IR) $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
      TDUM=1.0/(PERC*VUR*A6*A9) $ IF(I1.LE.0)I1=1
      DO 80 INUC=1,12
      IF(BAS(ISTR,INUC+4).LT.1.E-14)GO TO 80
      TDUR=TDUM/FMF(INUC) $ CALL ZERO(DMY,60)
      C1=TDUR $ IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 15
      IF(C1.LT.GINS)C1=GINS
C
```

Listing for GRWATER Computer Code (continued)

```
C     SUBROUTINE RTIJ CALCULATES THE MIGRATION REDUCTION FACTOR
C     RESULTS ARE RETURNED IN RES MATRIX.
C
   15 CALL RTIJ(TYMD,NTYM,INUC,IR,I1,C1,0.,RES,GDFL)
      B1=BAS(ISTR,3)*BAS(ISTR,INUC+4)/TDUR
      DO 30 IPTH=1,3
      B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
      DO 25 ITYM=1,NTYM
      A3=EXM(AL(INUC)*TYMD(ITYM))
      DO 20 I=1,7
      A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
      DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
   20 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
   25 CONTINUE
   30 CONTINUE
C
C     THE NEXT SECTION CONSIDERS (OPTIONAL BY NOPT) THE SECOND
C     SOURCE TERM OF A 2-STEP ANALYSIS WITH AN INCREASED SOURCE
C     TERM (PER2) AFTER THE INSTITTUTIONAL CONTROL PERIOD.
C
      IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 60
      IF(TDUR.LE.GINS)GO TO 60
      T1=GINS $ T2=T1+PERC*(TDUR-T1)/PER2
      CALL RTIJ(TYMD,NTYM,INUC,IR,I1,T2,T1,RES,GDFL)
      B1=B1*PER2/PERC
      DO 50 IPTH=1,3
      B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
      DO 45 ITYM=1,NTYM
      A3=EXM(AL(INUC)*TYMD(ITYM))
      DO 40 I=1,7
      A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
      DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
   40 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
   45 CONTINUE
   50 CONTINUE
   60 WRITE(3,102) NUC(INUC)
      WRITE(3,103) ((DMY(I,J),J=1,NTYM),I=1,3)
   80 CONTINUE
   90 CONTINUE
C
C     END OF MAIN LOOP
C
  101 FORMAT(2X,A10,E10.3,2I5)
  102 FORMAT(2X,A7)
  103 FORMAT(9X,9E9.2)
      RETURN $ END
C
C
      SUBROUTINE RTIJ(TYMD,NTYM,INUC,IR,I1,TDUR,TMIN,RES,GDFL)
      COMMON/NUCS/NUC(23),AL(23),EMF(23),RET(23,5)
+           /DTIS/FSCA(42),TTM(6,3),TPC(6,3),RGFP(36),DTTM(6),DTPC(6)
      DIMENSION TYMD(NTYM),RES(18,3),RTTM(6),RTPC(6)
```

Listing for GRWATER Computer Code (continued)

```
      DATA BTTM/350.,66.,175.,283.,56.,116./,
     +     BTPC/700.,1900.,700.,1600.,1900.,1900./,NOPTW/0/
C
C     NOPTW=0 SIGNIFIES INTRUDER WELL
C     NOPTW=1 SIGNIFIES BOUNDARY WELL (BTTM,BTPC)
C
      CALL ZERO(RES,54)
      DO 30 IPTH=1,3
      A1=RET(INUC,I1)*TTM(IR,IPTH)+GDEL
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) A1=RET(INUC,I1)*BTTM(IR)+GDEL
      DO 20 ITYM=1,NTYM
      TYM=TYMD(ITYM)-TMIN $ A2=TYMD(ITYM)-TDUR
      DO 10 ISEC=1,10
      B3=1.0/(A1+RET(INUC,I1)*(ISEC-1)*DTTM(IR))
      IF(TYM*1.1*B3.LT.1.0) GO TO 20
      B4=TPC(IR,IPTH)+(ISEC-1)*DTPC(IR)
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) B4=BTPC(IR)+(ISEC-1)*DTPC(IR)
      A3=0.5*ERFS(B3*TYM,B4)
      IF(A2.GT.0.)A3=A3-0.5*ERFS(B3*A2,B4)
      IF(A3.LT.0.)A3=0.
   10 RES(ITYM,IPTH)=RES(ITYM,IPTH)+A3
   20 CONTINUE
   30 CONTINUE
      RETURN $ END
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
```

Listing for OPTIONS Computer Code

```
      PROGRAM OPTIONS(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C     FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCKS.
C     TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
C     TAPE3 READS IN THE DISPOSAL TECHNOLOGY CASES
C     TAPE4 CONTAINS PROGRAM OUTPUT.
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IPDC(12)
+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+                  PGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+            /VOL/VREG,VLAY,VHOT
+            /IMPS/DZ(8,7,2),DZO(4,7,2),DZA(7,7),DZS(36,7,2)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
C     VOL BLOCK CONTAINS TOTAL REGULAR, LAYERED, AND HOT WASTE VOLUMES.
C     IMPS IS EXPLAINED BELOW:
C     DZ(8,7,2)   = OUTPUT FROM SUBROUTINE RCLAIM TO MAIN PROGRAM
C                   CONTAINING INTRUDER IMPACTS FOR SEVEN ORGANS
C                   AND TWO PATHWAYS UNDER EIGHT TESTING CONDITIONS.
C     DZO(4,7,2) = THIS MATRIX IS USED TO VOLUME AVERAGE THE OUTPUT
C                   DOSES FROM RCLAIM. FINAL VALUES ARE FOR SEVEN ORGANS
C                   AND TWO PATHWAYS AT THREE TIME STEPS (IIC, 500,
C                   1000 YEARS) AND SUBSEQUENTLY PRINTED OUT TO TAPE4.
C     DZA(7,7)    = OUTPUT FROM SUBROUTINE ACCEXP TO MAIN PROGRAM
C                   CONTAINING THE ACCIDENT AND EXPOSURE DOSES FOR
C                   SEVEN ORGAN AND SEVEN PATHWAYS.
C     DZS(36,7,2) = OUTPUT FROM SUBROUTINE ACCEXP FOR THE TWO
C                    ACCIDENT PATHWAYS CONSIDERED BY ALL STREAMS (36)
C                    AND 7 ORGANS.
      DIMENSION IQR(36),IQL(36),IQH(36),IQN(36),G(4),D(4)
      DIMENSION NOTE(6),DES(9),TIMP(6),COST(5),UN(5),NDX(36)
C
C     THESE ARRAYS ARE EXPLAINED BELOW:
C     IQR(36), IQL(36) = INDICES OF STREAMS BELONGING TO EACH
C     IQH(36), IQN(36)   OF THE FOUR WASTE TYPES (REGULAR, LAYERED,
C                        HOT, AND NOT ACCEPTABLE)
C     NOTE(6)          = HEADER INFORMATION READ IN THRU INPUT AND
C                        PRINTED OUT ON TOP OF OUTPUT FOR IDENTIFICATION.
C     DES(9)           = DESCRIPTION OF 9 PATHWAYS CONSIDERED.
C     TIMP(6)          = TRANSPORTATION IMPACTS CALCULATED IN SUBROUTINE
C                       TRANSP AND PASSED TO MAIN PROGRAM.
C     COST(5)          = DISPOSAL IMPACTS CALCULATED IN SUBROUTINE ECON.
C     G(4),D(4)        = LOCAL ARRAYS WHICH ACCUMULATES PROCESSING IMPACT.
C                        G FOR PROCESSING AT GENERATOR AND D FOR PROCESSING
C                        AT THE DISPOSAL SITE
C     UN(5)            = UNIT COSTS ($/M3) FOR PROCESSING, TRANSPORTATION,
C                        DISPOSAL DURING OPERATIONAL PERIOD, AND DISPOSAL
C                        DURING POST CLOSURE PERIOD.
C     NDX              = STREAM CONTROL ARRAY
C                          0 = DELETE STREAM FROM CONSIDERATION
C                          1 = PROCEED AS NORMAL
C                          2 = HIGH INTEGRITY CONTAINER
C                          3 = STABLIZED
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
C
      DATA DES/10H REC-CONS ,10H REC-AGRI ,
+              10H REC-AIR  ,10H ERO-AIR  ,10H REC-WAT  ,
+              10H ERO-WAT  ,10H ACC-SNGC ,10H ACC-FIPE ,10H ACC-AVG
      DATA RI,RJ/.1,.09/
      DATA NDX/36*1/
C
C     SUBROUTINE COMBYN READS IN MOST OF THE INPUT DATA
C     AND CALCULATES THE PROCESSING IMPACTS. PROCESSING IMPACTS
C     ARE RETURNED IN BAS(ISTR,29) THRU BAS(ISTR,32).
C
      CALL COMBYN(NSTR,NNUC,NDX)
C
      READ(3,)NCASE
      DO 300 NC=1,NCASE
      READ(3,1002)NOTE $ READ(3,)IRDC
      WRITE(4,1003)NOTE,IRDC
      CALL ZERO(DZ,721)
      VREG=0. $ VLAY=0. $ VHOT=0. $ VNOT=0.
      NREG=0  $ NLAY=0  $ NHOT=0  $ NNOT=0
C
C
C     NEXT SECTION CALCULATES THE INTRUDER IMPACTS AND DETERMINES
C     THE WASTE STREAM STATUS - ISPC(ISTR,11).
C
C
      DO 50 ISTR=1,NSTR
      IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
      IDX=NDX(ISTR) $ IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD,IDX)
      II=ISPC(ISTR,11)+1 $ GO TO (10,20,30,40),II
   10 NNOT=NNOT+1               $ ION(NNOT)=ISTR
      VNOT=VNOT+BAS(ISTR,3) $ GO TO 50
   20 NREG=NREG+1               $ IOR(NREG)=ISTR
      DO 25 I=1,7
      DO 25 J=1,2
      DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
      DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
   25 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VREG=VREG+BAS(ISTR,3) $ GO TO 50
   30 NLAY=NLAY+1               $ IOL(NLAY)=ISTR
      DO 35 I=1,7
      DO 35 J=1,2
      DZQ(4,I,J)=DZQ(4,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
      DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
   35 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VLAY=VLAY+BAS(ISTR,3) $ GO TO 50
   40 NHOT=NHOT+1               $ IOH(NHOT)=ISTR
      DO 45 I=1,7
      DO 45 J=1,2
      DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
   45 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VHOT=VHOT+BAS(ISTR,3)
   50 CONTINUE
      IF(VLAY.EQ.0.) VLAY=1.
```

```
      DO 55 J=1,7
      DO 55 K=1,2
      DZQ(1,J,K)=DZQ(I,J,K)/(VREG+VHOT)
      IF(VLAY.GT.1.) DZQ(1,J,K)=DZQ(1,J,K)+DZQ(4,J,K)/VLAY
      DZQ(2,J,K)=DZQ(2,J,K)/(VREG+VLAY)
   55 DZQ(3,J,K)=DZQ(3,J,K)/(VREG+VLAY+VHOT)
C
C     THE MATRIX DZQ NOW CONTAINS THE VOLUME AVERAGED INTRUDER IMPACTS.
C
      IF(VLAY.EQ.1.) VLAY=0.
      IF(NREG.GT.0) CALL PRT(VREG,IQR,NREG,1,NDX)
      IF(NLAY.GT.0) CALL PRT(VLAY,IQL,NLAY,2,NDX)
      IF(NHOT.GT.0) CALL PRT(VHOT,IQH,NHOT,3,NDX)
      IF(NNOT.GT.0) CALL PRT(VNOT,IQN,NNOT,4,NDX)
      WRITE(4,1008)
      DO 70 I=1,3
      DO 65 K=1,2
      A1=0.
      DO 60 J=1,7
   60 A1=A1+DZQ(I,J,K)*FICRP(J)
   65 WRITE(4,1009) DES(K),(DZQ(I,J,K),J=1,7),A1
   70 CONTINUE
C
C     NEXT SECTION CALCULATES THE DOSES FOR THE ACCIDENT AND EXPOSURE
C     SCENARIOS - CONSISTS OF SEVEN PATHWAYS FOR SEVEN ORGANS.
C
      CALL ACCEXP(NSTR,NNUC,NDX)
      WRITE(4,1014)
      DO 100 K=1,7
      KK=K+2 $ A1=0.
      DO 95 J=1,7
   95 A1=A1+DZA(J,K)*FICRP(J)
  100 WRITE(4,1015)DES(KK),(DZA(J,K),J=1,7),A1
C
C     NEXT SECTION CALCULATES THE TRANSPORTATION IMPACTS AND THE
C     DISPOSAL IMPACTS THRU SUBROUTINES TRANSP AND ECON, RESPECTIVELY.
C
      CALL TRANSP(TIMP,NSTR)
      CALL ZERO(G,4) $ CALL ZERO(D,4)
      DO 110 I=1,NSTR
      I1=ISPC(I,10) $ I2=I1/100
      I3=(I1/10)-I2*10 $ IF(I3.EQ.0) GO TO 110
C
C     SEPERATE GENERATOR AND DISPOSAL PROCESSING IMPACTS
C
      IF(I3.EQ.2) GO TO 105
      G(1)=G(1)+BAS(I,29) $ G(2)=G(2)+BAS(I,30)
      G(3)=G(3)+BAS(I,31) $ G(4)=G(4)+BAS(I,32)
      GO TO 110
  105 D(1)=D(1)+BAS(I,29) $ D(2)=D(2)+BAS(I,30)
      D(3)=D(3)+BAS(I,31) $ D(4)=D(4)+BAS(I,32)
  110 CONTINUE
C
      CALL ECON(NSTR,RI,RJ,COST,NDX)
C
```

Listing for OPTIONS Computer Code (continued)

```
C
C      PROCESSING, TRANSPORTATION, AND DISPOSAL IMPACTS ARE NOW BROUGHT
C      TOGETHER AND PRINTED OUT.
C
       VT=VREG+VLAY+VHOT
       UN(1)=G(1)/VT $ UN(2)=D(1)/VT
       UN(3)=TIMP(1)/VT $ UN(4)=COST(1)/VT $ UN(5)=COST(5)/VT
       COST(2)=COST(2)+TIMP(5) $ X=0.
       TIMP(3)=TIMP(3)+TIMP(6)
       WRITE(4,1013)RI,RJ,G(1),D(1),TIMP(1),COST(1),COST(5),
+      UN(1),UN(2),UN(3),UN(4),UN(5),G(4),D(4),TIMP(4),X,
+      G(3),D(3),TIMP(3),COST(2),X,X,X,COST(4),G(2),D(2),TIMP(2),COST(3)
C
       DO 120 K=1,2
       IF(K.EQ.1)WRITE(4,1016)
       IF(K.EQ.2)WRITE(4,1017)
       WRITE(4,1018)
       DO 120 I=1,NSTP
       A1=0.
       DO 115 J=1,7
  115  A1=A1+D7S(I,J,K)*FICRP(J)
       WRITE(4,1020)BAS(I,1),(D7S(I,J,K),J=1,7),A1
  120  CONTINUE
  300  CONTINUE
 1001  FORMAT(12I3)
 1002  FORMAT(6A10)
 1003  FORMAT(1H1/2X,6A10//2X*DISPOSAL TECHNOLOGY INDICES*/2X,
+                          *IP =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                          *IF =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                          *IH =*I2*  ICL=*I2*  IPO=*I2*  IIC=*I4)
 1008  FORMAT(1H1/2X,*INTRUDER IMPACTS*,7X,*BODY       BONE       LIVER*
+      *    THYROID    KIDNEY     LUNG     G-I TRACT    ICRP*)
 1009  FORMAT(12X,A10,8E10.3)
 1013  FORMAT(/2X*OTHER IMPACTS        WASTE PROCESSING     TRANSP    *,
+      *DISPOSAL    LT CARE*,2X,2F5.3/16X*      GENERAT   DISPOSAL*/2X,
+      *COST ($)*8X,5E10.2/2X*UNIT COST ($/M3)*5E10.2/2X*POP DOSE (MREM) *,
+      4E10.2/2X*OCC DOSE (MREM) *4F10.2/2X,16HLAND USE (M**2) ,4F10.2/2X,
+      *ENERGY USE (GAL)*4F10.2)
 1014  FORMAT(/2X*EXPOSE/ACC IMPACTS*)
 1015  FORMAT(12X,A10,8E10.3)
 1016  FORMAT(//2X*SINGLE CONTAINER ACCIDENT - ALL STREAMS*)
 1017  FORMAT(//2X*ACCIDENT BY FIRE - ALL STREAMS*)
 1018  FORMAT(14X,*STREAM*,5X,*BODY       BONE       LIVER     THYROID    *
+      *KIDNEY     LUNG     G-I TRACT    ICRP*)
 1020  FORMAT(12X,A10,8E10.3)
       STOP $ END
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
      SUBROUTINE COMBYN(NSTR,NNUC,NDX)

      THIS SUBROUTINE READS THE DATA FILES, TAPE1 AND TAPE2, AND
      PERFORMS SEVERAL BASIC CALCULATIONS TO INTEGRATE SOME OF
      THE INFORMATION.  IT PERFORMS THE FOLLOWING:
      1 : READ THE COMMON BLOCKS BAST, NUCS, AND DTIS
      2 : USING THE VRF AND VIF GIVEN IN ISPC MATRIX MODIFIES
          VOLUMES AND CONCENTRATIONS
      3 : CALCULATES TRANSPORTED VOLUME AND STORES IT ON BAS(ISTR,28)
      4 : CALCULATES THE WASTE PROCESSING IMPACTS
      5 : MODIFIES H-3 AND C-14 CONC IF WASTE IS INCINERATED
      6 : CALCULATES THE RET(23,5) MATRIX FROM GIVEN INFORMATION.

      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
            PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),
            DTPC(6),TPO(6,2),NRET(6)
      DIMENSION AZR(36),UPRS(7,3),USOL(3,3),USAV(3),
                DEC(23,2),TPOP(2),NDX(36)


      ADDITIONAL INFORMATION NECESSARY FOR THIS ROUTINE ARE GIVEN
      IN THE ARRAYS AND DATA STATEMENTS.  THE ARRAYS ARE FOLLOWING:
      AZR(36)    = SPECTRUM 1 VIF/VRF RATIOS
      UPRS(7,3)  = VOLUME REDUCTION UNIT IMPACTS
      USOL(3,3)  = SOLIDIFICATION UNIT IMPACTS
      USAV(3)    = UNIT SAVINGS RESULTING FROM VOLUME REDUCTION
      DEC(23,1)  = DECON FACTORS FOR PATHOLOGICAL INCINERATOR,
                   AND DEC(23,2) IS THE DECON FACTORS FOR CALCINER.
      TPOP(2)    = PERSON-YEAR/M3 ATMOSPHERIC DISPERSION FACTORS
      FOR POPULATION EXPOSURE CALCULATION FOR URBAN AND RURAL AREAS.

      DATA AZR/1.,1.4,3*1.,1.4,15*1.,4*3.,2*1.92,3*1.,2.,1.3,4*1./
      DATA UPRS/335.,503.,1006.,690.,2060.,1938.,1039.,3*4.6,
           56.3,116.,129.,72.,3*15.,4.42,8.,6.12,5.35/,
      USOL/1282.,1873.,2445.,3*40.,3*24./,
      USAV/210.,.4,4./,TPOP/1.56E-8,1.56E-10/,DEC/.9,.75,6*2.5E-3,
         2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
      READ(1,101)NSTR,NNUC,FICRP
      DO 70 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
      READ(2,103)(ISPC(I,J),J=1,10)
   70 CONTINUE
      DO 80 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 75 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   75 CONTINUE
   80 CONTINUE
      DO 90 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
      (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3),
      NRET(I),DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   90 CONTINUE
```

Listing for OPTIONS Computer Code (continued)

```
  101 FORMAT(2I5,7F5.2)
  102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
  103 FORMAT(10X,10I5)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6F10.3/10X,6E10.3,I5/10X,4E10.3)
  106 FORMAT(10X,7E10.3)
      DO 50 ISTR=1,NSTR
      A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
      A2=BAS(ISTR,3)/3.62 $ A3=A2/A1 $ BAS(ISTR,3)=A3
      DO 20 I=5,27
   20 BAS(ISTR,I)=BAS(ISTR,I)*A1
      BAS(ISTR,28)=BAS(ISTR,3) $ J=ISPC(ISTR,10)
C
C     THE FACTOR 3.62 IS THE NORMALIZATION VALUE
C     FOR ONE MILLION CUBIC METERS.
C     THE NEXT SECTION UNSCRAMBLES THE PROCESSING INDEX AND GETS
C     THE VOLUME REDUCTION METHOD - IP, SOLIDIFICATION - IS,
C     LOCATION - IL, AND ENVIRONMENT - IH.  IF IL=0 THEN THERE IS
C     NO PROCESSING AND THE SECTION IS SKIPPED, IF IL=2 THEN
C     THE DISPOSAL AND TRANSPORTATION VOLUMES ARE DIFFERENT
C
      BAS(ISTR,4)=BAS(ISTR,4)*A1
      IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
      IH=J-IP*1000-IS*100-IL*10 $ IF(NDX(ISTR).EQ.2)GO TO 31
      IF(IL.EQ.0) GO TO 50
      IF(IL.NE.2) GO TO 25
      BAS(ISTR,28)=A2 $ BAS(ISTR,4)=BAS(ISTR,4)/A1
   25 A5=0.5 $ IF(ISTR.GT.11)A5=0.1
C
C     NEXT DO LOOP CALCULATES WASTE PROCESSING IMPACTS
C
      DO 30 J=1,3
      A4=-A3*(AZR(ISTR)*A1-1.)*USAV(J)
      IF(IP.GT.0)A4=A4+A2*UPRS(IP,J)
      IF(IS.GT.0)A4=A4+A3*USOL(IS,J)
      IF(J.EQ.3)A4=A4*A5
   30 BAS(ISTR,28+J)=A4
C
C     NEXT SECTION FOR STREAMS PUT IN HIGH INTEGRITY CONTAINERS
C
   31 IF(NDX(ISTR).NE.2) GO TO 32
      A4=A2*450.
      BAS(ISTR,29)=A4
      IF(IL.EQ.0) GO TO 50
   32 CONTINUE
C
C     NEXT SECTION SKIPPED IF WASTE IS NOT INCINERATED
C     OTHERWISE, LOCATION DEPENDENT POP DOSES ARE CALCULATED
C
      IF(IP.LT.5)GO TO 50
      A5=0. $ J=2 $ IF(IP.EQ.5)J=1
      IF(IH.NE.1.AND.IH.NE.2)IH=1
      DO 40 INUC=1,NNUC
      A4=BAS(ISTR,3)*BAS(ISTR,INUC+4)*DEC(INUC,J)*TPOP(IH)
      DO 40 I=1,7
   40 A5=A5+A4*FICRP(I)*DCF(INUC,I,8)
      BAS(ISTR,32)=A5
```

Listing for OPTIONS Computer Code (continued)

```

      ONLY ICRP WEIGHTED POPULATION IMPACTS ARE CALCULATED
      ABOVE, TWO STATEMENTS BELOW MODIFY H-3 AND C-14
      CONCENTRATIONS TO ACCOUNT FOR LOSS UP THE STACK.

      BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
      BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
   50 CONTINUE
      RETURN $ END


      SUBROUTINE RCLAIM(ISTR,NNUC,IMOD,IDX)

      THIS ROUTINE CALCULATES THE INTRUDER IMPACTS FOR TWO PATHWAYS
      - CONTRUCTION AND AGRICULTURE - AND DETERMINES THE STATUS OF
      EACH WASTE STREAM ISPC(ISTR,11) AND DETERMINING TEST
      CONDITION (IMOD).

      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
            /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
            /DTIS/FSC(6),FSA(6)/IMPS/DZ(8,7,2)
      DIMENSION EMP(5),DLC(7)

      DATA EMP/.5,.75,.5,.5,.75/,DLC/2*500.,1500.,3000.,3*1500./
      I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
      I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
      IF(IDX.GT.1) I8=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      CALL ZERO(DZ,112) $ IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
      FDES=EMP(IE)*(1.-.9*IG)
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)

      NEXT SECTION CALCULATES INTRUDER IMPACTS UNDER EIGHT
      CONDITIONS (LOOP 35) AND SUBSEQUENTLY TESTS FOR STATUS ASSIGNMENT.
      ULTIMATELY WASTE STREAM WILL BE CLASSIFIED AS EITHER NOT
      ACCEPTABLE,REGULAR,LAYERED, OR HOT.

      DO 35 I3=1,8
      GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      GO TO (11,12,13,14,15,16,17,18),I3
   11 A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
   13 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   14 A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
   15 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
   16 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   17 A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=A8C*0.1
      A4C=0.01 $ A4A=0. $ A8A=0. $ GO TO 20
   18 GDEL=IPO+1000. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A7
      A4C=1. $ A4A=1. $ A8A=A8C
```

Listing for OPTIONS Computer Code (continued)

```
   20 DO 30 INUC=1,NNUC
      A1=A9*FDES*EXM(AL(INUC)*GDEL)*RAS(ISTR,INUC+4)
      DO 25 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      B2=A1*A8C*A2*0.057
      B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
C     B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C     B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
C     B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)
      B5=0.25*A1*A8A*A2*0.27
      DZ(I3,I,1)=DZ(I3,I,1)+B1+B2
   25 DZ(I3,I,2)=DZ(I3,I,2)+B3+B4+B5
   30 CONTINUE
   35 CONTINUE
C
C     ALL CONDITIONS TESTED - NOW DETERMINE WASTE STATUS
C
      I3=1 $ IF(IS.EQ.1.AND.IR.EQ.1) I3=2
      IF(ID.EQ.2) I3=2
      I30=I3
      IF(IDX.EQ.0) GO TO 70
   40 DO 50 IORG=1,7
      DO 50 IPTH=1,2
      IF(DZ(I3,IORG,IPTH).GT.DLC(IORG)) GO TO 60
   50 CONTINUE
      GO TO (51,52,51,53,53,54,55,56),I3
   51 ISPC(ISTR,11)=1
      IMOD=1 $ IF(I30.EQ.2) IMOD=2
      RETURN
   52 I3=3 $ GO TO 40
   53 I3=6 $ GO TO 40
   54 ISPC(ISTR,11)=2
      IMOD=4 $ IF(I30.EQ.2) IMOD=5
      RETURN
   55 I3=8 $ GO TO 40
   56 ISPC(ISTR,11)=3 $ IMOD=7
      RETURN
   60 GO TO (61,62,63,63,63,63,70,70),I3
   61 IF(IL.EQ.0)GO TO 63
      I3=4 $ GO TO 40
   62 IF(IL.EQ.0)GO TO 63
      I3=5 $ GO TO 40
   63 IF(IH.EQ.0)GO TO 70
      I3=7 $ GO TO 40
   70 ISPC(ISTR,11)=0
      RETURN $ END
C
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
      SUBROUTINE ACCEXP(NSTR,NNUC,NDX)
C
C     THIS ROUTINE CALCULATES THE EXPOSURE AND ACCIDENT IMPACTS
C     FOR 7 PATHWAYS (4 EXPOSURE AND 3 ACCIDENT) AND 7 ORGANS.
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
+           TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6
+           /IMPS/DZDM(168),DZA(7,7),DZS(36,7,2)
      DIMENSION EMP(5),EFF(2),SEFF(2),NDX(36)
      DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/
      VTOP=0. $ VTOT=0. $ VHOT=0. $ GREC=IPO+IIC
C
C     EROSION TIME SCALE DEPENDENT ON COVER USED AT DISPOSAL SITE
C
      GERO=IPO+2000.
      IF(IC.EQ.2) GERO=IPO+3000.
      IF(IC.EQ.3) GERO=IPO+10000.
      IF(ID.EQ.2) GERO=IPO+10000.
      DO 10 ISTR=1,NSTR
      I1=ISPC(ISTR,11)
      IF(I1.EQ.1)VTOP=VTOP+BAS(ISTR,3)
      IF(I1.EQ.1.OR.I1.EQ.2)VTOT=VTOT+BAS(ISTR,3)
      IF(I1.EQ.3)VHOT=VHOT+BAS(ISTR,3)
   10 CONTINUE
C
C     VTOP IS JUST REGULAR WASTE
C     VTOT IS REGULAR + LAYERED WASTE
C
C
C     NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
C
      FRA=5.72E-5*POP(IR,1)*1.8E+3 $ VUR=EMP(IE)*EFF(ID)*SEFF(ID)
      FEA=8.09E-6*POP(IR,2)*VTOT/VUR
      FRW=1.15E-4*POP(IR,3)*1.8E+3
      FEW=1.15E-4*POP(IR,3)*VTOT/VUR
C
C     MAIN LOOP FOR EXPOSURE IMPACTS
C
      DO 40 ISTR=1,NSTR
      A1=0.25 $ I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 40
      I5=ISPC(ISTR,5) $ A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      I9=ISPC(ISTR,9) $ A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
      I8=ISPC(ISTR,8) $ IF(NDX(ISTR).GT.1) I8=1
      IF(I8.EQ.1.AND.IS.EQ.1)A1=0.012/9.
      IF(I11.EQ.2.OR.ID.EQ.2)A1=A1*0.01
      IF(I11.EQ.3)A1=1.2E-5/9.
      A2=EMP(IE)*SEFF(ID)*BAS(ISTR,3)/VTOP
      A3=A2*VTOP/(VTOT+VHOT) $ IF(I11.GT.1)A2=0.
      IF(ID.EQ.2.AND.I11.NE.2) A2=A3
```

Listing for OPTIONS Computer Code (continued)

```
      DO 30 INUC=1,NNUC
      A6=EXM(GREC*AL(INUC)) $ A7=EXM(GERO*AL(INUC))
      A8=BAS(ISTR,INUC+4)
      B1=FRA*A1*A3*A6*A8*A5      $ B2=FEA*A2*A7*A8
      B3=FRW*A1*A3*A6*A8*A9      $ B4=FEW*A2*A7*A8
      DO 20 IORG=1,7
      DZA(IORG,1)=DZA(IORG,1)+B1*DCF(INUC,IORG,8)
      DZA(IORG,2)=DZA(IORG,2)+B2*DCF(INUC,IORG,8)
      DZA(IORG,3)=DZA(IORG,3)+B3*DCF(INUC,IORG,7)
      DZA(IORG,4)=DZA(IORG,4)+B4*DCF(INUC,IORG,7)
   20 CONTINUE
   30 CONTINUE
   40 CONTINUE
C
C     END EXPOSURE LOOP
C
      VSC=0. $ VFR=0.
C
C     MAIN LOOP OF ACCIDENT IMPACTS
C
      DO 80 ISTR=1,NSTR
      I3=ISPC(ISTR,11) $ IF(I3.EQ.0.OR.I3.EQ.3)GO TO 80
      I4=ISPC(ISTR,4) $ I6=ISPC(ISTR,6) $ I9=ISPC(ISTR,9)
      A5=BAS(ISTR,3) $ IF(I9.GT.1) GO TO 80
      FAF=TPO(IR,1) $ FAS=TPO(IR,2)
      IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
      IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
      IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
C
C     DISTINGUISH BETWEEN SINGLE CONTAINER AND FIRE ACCIDENTS
C
      VFR=VFR+A5
      VSC=VSC+A5
      DO 70 INUC=1,NNUC
      A1S=FAS*BAS(ISTR,INUC+4)*A5
      A1F=FAF*BAS(ISTR,INUC+4)*A5
      DO 70 IORG=1,7
      DZS(ISTR,IORG,1)=DZS(ISTR,IORG,1)+A1S*DCF(INUC,IORG,1)/A5
      DZS(ISTR,IORG,2)=DZS(ISTR,IORG,2)+A1F*DCF(INUC,IORG,1)/A5
      DZA(IORG,5)=DZA(IORG,5)+A1S*DCF(INUC,IORG,1)
   70 DZA(IORG,6)=DZA(IORG,6)+A1F*DCF(INUC,IORG,1)
   80 CONTINUE
C
C     END OF ACCIDENT LOOP
C
C
C     LAST PATHWAY IS AVERAGED ACCIDENT
C
      DO 90 IORG=1,7
      DZA(IORG,7)=(DZA(IORG,5)+DZA(IORG,6))/(VSC+VFR)
      IF(VSC.GT.0.) DZA(IORG,5)=DZA(IORG,5)/VSC
      IF(VFR.GT.0.) DZA(IORG,6)=DZA(IORG,6)/VFR
   90 CONTINUE
      RETURN $ END
C
```

Listing for OPTIONS Computer Code (continued)

```

      SUBROUTINE TRANSP(TIMP,NSTR)

      THIS ROUTINE DETERMINES THE TRANSPORTATION SCHEME FOR ALL
      WASTE STREAMS BASED PRIMARILY ON THE PACKAGING INDEX OF
      THE SPECTRUM FILES AND THE ACTIVITY CONCENTRATIONS OF THE
      INDIVIDUAL STREAMS. ULTIMATE RESULT IS THE TRANSPORTATION
      IMPACTS (TIMP).

      COMMON/BAST/BAS(36,32),ISPC(36,11)/DTNX/IR,ID,IC,IX,IF
      DIMENSION PCAR(6,3),PPAK(8,6),KON(18),TYM(2,18),KWT(18),
      PDZ(2,3),PKV(5),TDZ(2,2),TCST(2,3),TIMP(6),TVOL(5,3),
      DUM1(3),DUM2(3),DUM3(3,3),DIST(6),STPS(6),CASK(6)

      THE ABOVE ARRAYS AND MATRICES ARE EXPLAINED BELOW:
            PCAR(6,3)     : CONTAINS 6 DISTRIBUTIONS OF 3 CARE TYPES.
            PPAK(8,6)     : CONTAINS 8 DISTRIBUTIONS OF 5 PACKING
                            CONTAINERS + A POSITIONING INDEX.
            KON(18)       : MULTIPLE INDEX WHICH DESCRIBES PACKING
                            CAPABILITIES FOR 3 CARE TYPES AND 5
                            CONTAINERS.
            TYM(2,18)     : TIME IN MINUTES FOR UNLOADING OF WASTE
                            (CONTACT TIME) - CORRESPONDING TO THE
                            18 KON INDICES ABOVE.
            TCST(2,3)     : TRANSPORTATION COST ($) PER MILE.
            RDZ(2,3)      : RADIOLOGICAL COST (DOSE) PER HOUR OF
                            CONTACT TIME WITH WASTE.
            TDZ(2,2)      : TWO PART TRANSPORTATION DOSE: PER MILE,
                            AND LUMP SUM PARAMETERS.
            PKV(5)        : VOLUME CAPACITY FOR EACH OF 5 CONTAINERS.
            KWT(18)       : INDEX TO RELATE TRANSPORT VEHICLE OVER-
                            WEIGHT STATUS TO EACH OF KON INDICES.
            DIST(6)       : TRAVEL DISTANCE TO DISPOSAL SITE IN
                            VARIOUS REGIONS.
            STPS(6)       : STATE INSPECTION STOPS TO BE EXPECTED
                            WITHIN A PARTICULAR REGION.
            CASK(6)       : NUMBER OF DAYS A CASK WOULD BE REQUIRED
                            IN A PARTICULAR REGION.
            OTHER ARRAYS AND MATRICES DESCRIBED FURTHER ON IN PROGRAM.

      DATA PCAR/1.,.8,.4,.2,.1,0.,0.,.2,.5,.6,.5,.2,0.,0.,.1,.2,.4,.8/
      DATA PPAK/0.,.23,5*0.,1.,0.,.08,.025,5*0.,.69,.69,.975,.2,1.,
      3*0.,.15,0.,0.,.8,0.,.5,2*0.,.16,4*0.,.5,1.,0.,3.,1.,2.,4*3.,1./
      DATA KON/1103024,1104076,1236100,1370100,1411100,-1501100,
            2103100,2236096,-2206004,2370048,-2314051,-2306001,
            -2402100,-2501100,-3306051,-3301049,-3402100,-3501100/
      DATA TYM/200.,240.,74.,120.,16.,24.,6.,24.,136.,165.,1200.,1440.,
            300.,360.,26.,39.,250.,300.,10.,24.,86.,175.,200.,312.,
            600.,720.,1200.,1440.,200.,312.,600.,720.,600.,720.,
            1500.,1800./,TCST/1.69,1.25,1.47,1.14,1.17,1.08/
      DATA RDZ/500.,750.,1200.,1800.,2200.,2200./,TDZ/1.8E-2,
            2.0E-2,2.,2./,PKV/3.625,.453,.208,1.416,4.814/
      DATA KWT/16*0,2*1/,DIST/300.,400.,600.,1000.,2*400./,
            STPS/2*1.,2.,3.,2*1./,CASK/2.,3.,5.,8.,2*3./
      CALL ZERO(TIMP,6) $ CALL ZERO(TVOL,15)

```

Listing for OPTIONS Computer Code (continued)

```
C     THIS SECTION -DO LOOP 160- DISTRIBUTES THE WASTE INTO THREE
C     CARE TYPES AND AMONG FIVE PACKING CONTAINERS. (3 CONTAINERS
C     ARE CONSIDERED IN EACH LOOP - IF APPLICABLE TO THAT STREAM.)
C
      DO 160 IPAK=1,8
      NX=0 $ CALL ZERO(DUM1,3)
C
C     DO LOOP 70 DISTRIBUTES WASTE AMONG CARE TYPES
C
      DO 70 ISTR=1,NSTR
      IF(ISPC(ISTR,11).EQ.0)GO TO 70
      I2=IABS(ISPC(ISTR,1))
      I1=I2/10 $ IF(I1.NE.IPAK)GO TO 70
      I3=I2-I1*10 $ A1=BAS(ISTR,28)
C
C     I1 = PACKAGING INDEX      I3 = CARE TYPE INDEX
C
C     FOLLOWING SECTION DETERMINES I4 - INDEX FOR CARE TYPE
C     DISTRIBUTION - BASED ON UNDECAYED TOTAL ACTIVITY OF STREAM.
C
      A2=BAS(ISTR,4)*100. $ IF(I3.EQ.2) A2=BAS(ISTR,4)*10.
      NX=1 $ IF(I3.GT.2) GO TO 40
      I5=ALOG10(A2)
      IF(I3.EQ.2) GO TO 30
      IF(A2.LT.1.) I4=1
      IF(A2.GE.1.) I4=I5+2
      IF(I4.GT.6) I4=6
      GO TO 50
   30 IF(A2.LT.1.) I4=1
      IF(A2.GE.1.) I4=I5+2
      IF(I4.GT.4) I4=4
      GO TO 50
   40 I4=I3-2
   50 DO 60 I=1,3
   60 DUM1(I)=DUM1(I)+PCAR(I4,I)*A1
   70 CONTINUE
C
C     DUM1 CONTAINES WASTE VOLUME IN EACH OF 3 CARE TYPES
C
      IF(NX.EQ.0) GO TO 160
      A1=DUM1(1)+DUM1(2)+DUM1(3)
      I2=PPAK(IPAK,6)+0.1
C
C     DO LOOP 80 DISTRIBUTES WASTE AMONG CONTAINERS
C
      DO 80 I=1,3
      II=I-1
   80 DUM2(I)=PPAK(IPAK,I2+II)*A1
C
C     DUM2 CONTAINS WASTE VOLUME IN EACH OF 3 CONTAINERS CONSIDERED
C     IN THIS LOOP OF 160
C
      CALL ZERO(DUM3,9)
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
C     DO LOOP 130 DETERMINES PACKAGING STRATEGY FOR 3 CARE TYPES AND
C     3 CONTAINERS CONSIDERED FOR THIS LOOP OF IPAK. RESULTS ARE
C     PLACED IN DUM3.
C
      DO 130 J=1,3
      DO 120 I=1,3
      IF(DUM1(J).LE.0.0) GO TO 130
      IF(DUM2(I).LE.0.0) GO TO 120
      IF(DUM1(J)-DUM2(I))90,100,110
   90 DUM3(I,J)=DUM1(J)
      DUM2(I)=DUM2(I)-DUM1(J)
      DUM1(J)=-1.0 $ GO TO 130
  100 DUM3(I,J)=DUM1(J)
      DUM2(I)=-1.0 $ DUM1(J)=-1.0 $ GO TO 130
  110 DUM3(I,J)=DUM2(I)
      DUM1(J)=DUM1(J)-DUM2(I)
      DUM2(I)=-1.0
  120 CONTINUE
  130 CONTINUE
      DO 150 I=1,3
      II=I-1
      DO 150 J=1,3
  150 TVOL(I2+II,J)=TVOL(I2+II,J)+DUM3(I,J)
  160 CONTINUE
C
C     TVOL CONTAINS TOTAL WASTE VOLUME DISTRIBUTED FOR 3 CARE TYPES
C     AND 5 CONTAINERS FOR ALL WASTE STREAMS.
C
C
C     THIS SECTION -DO LOOP 240- CALCULATES THE TRANSPORTATION
C     IMPACTS RESULTING FROM TVOL DISTRIBUTION. (18 LOOPS REQUIRED
C     FOR CHARACTERIZING THE 3 CARE TYPES AND 5 CONTAINERS USED
C     IN THIS PROGRAM)
C     RESULTS ARE PLACED IN TIMP ARRAY, WHERE:
C           TIMP(1) = DOLLARS
C           TIMP(2) = ENERGY USE
C           TIMP(3) = TRANSPORTATION OCCUPATIONAL DOSE
C           TIMP(4) = TRANSPORTATION POPULATION DOSE
C           TIMP(5) = DISPOSAL SITE OCCUPATIONAL DOSE (UNLOADING)
C           TIMP(6) = TRANSPORTATION OCCUPATIONAL DOSE (LOADING)
C
C
      DO 240 IKON=1,18
      II=KON(IKON) $ NX=1 $ FRC=1.0
C
C     IF KON INDEX IS NEGATIVE THEN RETURN TRIP IS NECESSARY.
C
      IF(II.GT.0) GO TO 210
      II=-II $ NX=2
  210 I3=II/100000 $ I2=I3/10 $ I1=I3-I2*10
      I5=II-I3*100000 $ I3=I5/1000 $ I4=I5-I3*1000
C
C     IN ABOVE SECTION KON BROKEN UP INTO:
C     I1 = PACKAGE TYPE       I3 = NO. OF PACKAGES THIS SHIPMENT
C     I2 = CARE TYPE          I4 = PCT. OF WASTE SENT THIS SHIPMENT
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
      IF((I2.EQ.1).OR.(I2.EQ.2.AND.NX.EQ.2)) FRC=0.1
      FRS=I4/100 $ A1=TVOL(I1,I2)*FRS
      IF(A1.LT.1.E-06) GO TO 240
      KSHP=A1/(I3*PKV(I1))+1.0
      A2=KSHP*DIST(IR) $ A3=A2*NX
      TIMP(2)=TIMP(2)+A3/6.
C
C     IN ABOVE EQUATION 6 REPRESENTS MILES PER GALLON FUEL CONSUMPTION.
C
      TIMP(4)=TIMP(4)+(A2*TDZ(1,1)+KSHP*TDZ(1,2)*STPS(IR))*FRC
      TIMP(3)=TIMP(3)+(A2*TDZ(2,1)+KSHP*TDZ(2,2)*STPS(IR))*FRC
      NC=3 $ IF(DIST(IR).GT.400..AND.DIST(IR).LT.1000.) NC=2
      IF(DIST(IR).LE.400.) NC=1
      TIMP(1)=TIMP(1)+A3*TCST(NX,NC)*1.15
C
C     IN NEXT SECTION CASK RENTAL FEE AND OVERWEIGHT FEE ADDED -
C     IF APPLICABLE.
C
      IF(NX.EQ.1) GO TO 220
      TIMP(1)=TIMP(1)+KSHP*CASK(IR)*250.
      IF(KWT(IKON).GT.0)TIMP(1)=TIMP(1)+A2*0.76+60.*STPS(IR)
  220 KPAK=A1/PKV(I1)+1.0
      NX=2 $ IF(IE.EQ.1.OR.IE.EQ.4) NX=1
      FRC=1.0 $ IF(IE.EQ.3) FRC=2.0
      A2=KPAK*TYM(NX,IKON)/60.
      TIMP(5)=TIMP(5)+A2*FRC*RDZ(NX,I2)*1.E-3
      TIMP(6)=TIMP(6)+A2*RDZ(2,I2)*1.E-3
  240 CONTINUE
      RETURN $ END
C
C
      SUBROUTINE ECON(NSTR,RI,RJ,COST,NDX)
C
C     THIS ROUTINE CALCULATES THE DISPOSAL IMPACTS BASED LARGELY
C     ON THE INPUTED VALUES FOR THE DISPOSAL TECHNOLOGY INDICES.
C     THE RESULTS OF THIS ROUTINE ARE PLACED IN ARRAY COST, WHERE:
C          COST(1) = PRE-OP AND OPERATIONAL DOLLARS
C          COST(2) = OCCUPATIONAL DOSE
C          COST(3) = ENERGY USE
C          COST(4) = LAND USE
C          COST(5) = POST-OP DOLLARS
C
      COMMON/BAST/BAS(36,32),ISPC(36,11)
      COMMON/DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
      COMMON/VOL/VREG,VLAY,VHOT
      DIMENSION EMP(5),EFF(2),AMULT(2),CONT(6),COST(5),SEFF(2)
      DIMENSION NDX(36)
C
C     THE SIGNIFICANT ARRAYS ABOVE ARE:
C     AMULT(2)   = CAPITAL AND OPERATIONS COST ($) MULTIPLIERS.
C     CONT(3)    = CONTINGENCY COST FOR SOIL PERMEABILITY CONDITIONS.
C     COST(5)    = CONTAINS RESULTANT IMPACTS - IN TERMS OF $,
C                  OCCUPATIONAL DOSE, ENERGY USE, LAND USE, AND
C                  POST OPERATIONAL $.
C
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
      RI AND RJ PARAMETERS ARE INTEREST AND INFLATION RATES, RESPECTIVELY.

      DATA CONT/1007.,367.,367.,0.,168.,1007./,ITO,F/20,.015/
      DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,AMULT/10.38,1.56/,
           SEFF/.9,.35/
      CALL ZERO(COST,5)
      VSTAB=0. $ VUNS=0. $ DECON=0.
      DO 5 ISTR=1,NSTR
      I11=ISPC(ISTR,11)  $ I2=ISPC(ISTR,8)
      IF(NDX(ISTR).GT.1) I2=1
      IF(I11.EQ.0.OR.I11.EQ.3) GO TO 5
      IF(IE.EQ.3.AND.I2.EQ.0) DECON=DECON+BAS(ISTR,3)
      IF(I2.EQ.0) VSTAB=VSTAB+BAS(ISTR,3)
      IF(I2.EQ.1) VUNS=VUNS+BAS(ISTR,3)
    5 CONTINUE
      IF(IE.EQ.3) IS=1

      VSTAB &_ VUNS CONTAIN STABLE AND UNSTABLE WASTE VOLUMES,RESPECTIVELY

      DREG=(VREG+VLAY)*1.E-06 $ DHOT=VHOT*1.E-06
      DLAY=VLAY*1.E-06         $ DECON=DECON*1.E-06
      DVOL=DREG/EMP(IE)        $ DAREA=DVOL/(EFF(ID)*SEFF(ID))
      GV=(1.-EMP(IE))*DVOL $ VTOT=VREG+VLAY+VHOT
      SV=DREG*((1.1567/EMP(IE))-1.)

      VOLUME AND AREA VALUES ARE EXPRESSED IN UNITS OF MILLION M3 OR M2
      FOR USE IN COST EVALUATIONS. GV IS GROUT VOLUME. SV IS SAND VOLUME.

      COST(4)= (DAREA            +(DHOT/1.84))*1.E6
      S1=(VSTAB/VREG)*DAREA $ S2=(VUNS/VREG)*DAREA

      IN FOLLOWING SECTION C1,C2, AND C3 WILL ACCUMULATE THE DOLLAR,
      DOSE, AND ENERGY COSTS THROUGH THE VARIOUS PHASES OF THE SITE LIFE.


      PRE-OPERATIONAL (CAPITAL) COSTS

      ******** REFERENCE BASE CASE ********
      C1=7452. $ COST(3)=212.
      ******** ADDITIVE ALTERNATIVES ******
      IF(ID.EQ.2) C1=C1+593.5
      IF(IE.EQ.2 .OR.IE.EQ.5) C1=C1+225.5
      IF(IS.EQ.1) C1=C1+0.99
      IF(IL.EQ.1) C1=C1+132.
      IF(IE.EQ.3) C1=C1+924.3
      IF(IW.EQ.1) C1=C1+259.4
      IF(IG.EQ.1) C1=C1+55.
      IF(IC.EQ.3) C1=C1+280.5
      IF(IX.EQ.3) C1=C1+9.9
      CAP=C1*AMULT(1)


```

```
C     OPERATIONAL COSTS
C
C     ********* REFERENCE BASE CASE *********
      C1=2341.*DVOL $ C2=300.*DVOL $ C3=200.*DVOL
      C1=C1+1420.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+100.*DAREA
      C1=C1+63696. $ C2=C2+1000. $ C3=C3+200.
C
C     ********* ADDITIVE ALTERNATIVES ******
      IF(ID.NE.2) GO TO 20
      C1=C1+74438.*DVOL $ C2=C2+700.*DVOL $ C3=C3+300.*DVOL
   20 IF(IE.LT.5.AND.NE.2) GO TO 25
      C1=C1+12758.*DREG $ C2=C2+100.*DREG $ C3=C3+100.*DREG
   25 IF(IS.NE.1) GO TO 30
      C1=C1+3888.*DREG $ C2=C2+100.*DREG $ C3=C3+30.*DREG
   30 IF(IL.NE.1) GO TO 35
      C1=C1+15400.*DLAY $ C2=C2*100.*DLAY $ C3=C3+30.*DLAY
   35 IF(IE.NE.3) GO TO 40
      C1=C1+48975.*DECON $ C2=C2+400.*DECON $ C3=C3+100.*DECON
   40 IF(IM.NE.1) GO TO 45
      C1=C1+176979.*DHOT $ C2=C2+(-200.)*DHOT $ C3=C3+450.*DHOT
   45 IF(IG.NE.1) GO TO 46
      C1=C1+72405.*GV $ C2=C2+2550.*GV $ C3=C3+800.*GV
   46 IF(IE.LT.4) GO TO 50
      C1=C1+3270.*SV $ C3=C3+150.*DAREA
   50 IF(IC.NE.2) GO TO 55
      C1=C1+15524.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+150.*DAREA
   55 IF(IC.NE.3) GO TO 60
      C1=C1+103854.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+300.*DAREA
   60 IF(IX.EQ.1) GO TO 75
      S3=S2
      IF(IS.EQ.0) S3=S1+S2
      IF(ID.EQ.2) S3=0.
      IXX=IX-1 $ GO TO (65,70),IXX
   65 C1=C1+3465.*S3 $ C2=C2+4800.*S3 $ C3=C3+300.*S3
      GO TO 75
   70 C1=C1+33345.*S3 $ C2=C2+4800.*S3 $ C3=C3+600.*S3
   75 OPS=C1*AMULT(2)
      COST(2)=COST(2)+C2 $ COST(3)=COST(3)+C3
C
C
C     POST-OPERATIONAL COSTS
C
C     ICL IS BROKEN INTO TWO PARTS TO INDICATE THE LEVEL OF
C     CLOSURE AND INSTITUTIONAL CARE, RESPECTIVELY.
C
C     ********* CLOSURE PERIOD *********
      ICL1=ICL/10 $ ICL2=ICL-ICL1*10
      C1=1010. $ C2=500. $ C3=15.
      IF(ICL1.NE.2) GO TO 76
      C1=3025. $ C2=1000. $ C3=60.
C
```

Listing for OPTIONS Computer Code (continued)

```
C      ********* INSTITUTIONAL PERIOD ****
C
C      DOLLAR COST SECTION
C
   76 CA=150. $ CB=63. $ CC=51.
      IF(ICL2.NE.2) GO TO 77
      CA=303. $ CB=150. $ CC=63.
   77 IF(ICL2.NE.3) GO TO 78
      CA=440.+CONT(IR) $ CB=303. $ CC=150.
   78 S1=0. $ S2=0. $ S3=0.
      DO 80 N=1,10
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   80 S1=S1+D1/D2
      DO 85 N=11,25
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   85 S2=S2+D1/D2
      DO 90 N=26,IIC
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   90 S3=S3+D1/D2
      PV80=CA*S1+CB*S2+CC*S3
      M=IPO+ITO
      EM=M $ EITO=ITO $ EIPO=IPO
      D1=(1.+RJ)**EITO $ D2=(1.+RJ)**EM
      D3=(1.+RI)**EITO $ D4=(1.+RI)**EIPO
      U3=(EITO*PV80*D2*RI)/((D3-1.)*D4)
      U3=(EITO*C1*D1*F) + U3
      COST(1)=CAP+OPS $ COST(5)=U3
C
C       ENERGY USE SECTION
C
      IICC=(IIC-26)+1
      GO TO (100,110,120),ICL2
  100 C3=C3+10*5.+15*3.+IICC*1.
      GO TO 125
  110 C3=C3+10*10.+15*5.+IICC*3.
      GO TO 125
  120 C3=C3+10*12.+15*10.+IICC*5.
  125 CONTINUE
      COST(1)=COST(1)*1000.
      COST(2)=COST(2)+C2 $ COST(5)=COST(5)*1000.
      COST(3)=COST(3)+C3 $ COST(3)=COST(3)*1000.
      RETURN $ END
C
C      UTILITY SUBROUTINES
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
```

<u>Listing for OPTIONS Computer Code</u> (continued)

```
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
      SUBROUTINE PRT(V,IQ,N,ID,NDX)
      COMMON/BAST/BAS(36,32),ISPC(36,11)
      DIMENSION IQ(36),LAB(4),NDX(36)
      DATA LAB/10HCH-STAR    ,10HCH-UNSTAR ,10HNCH-STAR  ,10HNCH-UNSTAB/
      IF(N.EQ.0)RETURN
      GO TO (10,10,50,70),ID
   10 IF(ID.EQ.1)WRITE(4,410)V
      IF(ID.EQ.2)WRITE(4,420)V
      DO 25 K=1,4
      IT=0 $ VTOT=0.
      DO 20 I=1,N
      ISTR=IQ(I)
      I8=ISPC(ISTR,8) $ I7=ISPC(ISTR,7)
      IF(NDX(ISTR).GT.1) I8=1
      IF(K.NE.1.AND.I7.EQ.1.AND.I8.EQ.1) GO TO 20
      IF(K.NE.2.AND.I7.EQ.1.AND.I8.EQ.0) GO TO 20
      IF(K.NE.3.AND.I7.EQ.0.AND.I8.EQ.1) GO TO 20
      IF(K.NE.4.AND.I7.EQ.0.AND.I8.EQ.0) GO TO 20
      IF(IT.EQ.0)WRITE(4,430)LAB(K),BAS(ISTR,1),BAS(ISTR,3)
      IF(IT.EQ.1)WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      IT=1 $ VTOT=VTOT+BAS(ISTR,3)
   20 CONTINUE
      IF(IT.EQ.1) WRITE(4,470)VTOT
   25 CONTINUE
      RETURN
   50 WRITE(4,450)V
      DO 55 I=1,N
      ISTR=IQ(I)
   55 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      RETURN
   70 WRITE(4,460)V
      DO 75 I=1,N
      ISTR=IQ(I)
   75 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
  410 FORMAT(/2X*REGULAR WASTE :*,21X,E10.3,5H M**3)
  420 FORMAT(/2X*LAYERED WASTE :*,21X,E10.3,5H M**3)
  430 FORMAT(7X,A10,A10,E10.3)
  440 FORMAT(17X,A10,E10.3)
  450 FORMAT(/2X*HOT WASTE     :*,21X,E10.3,5H M**3)
  460 FORMAT(/2X*NOT ACCEPTABLE:*,21X,E10.3,5H M**3)
  470 FORMAT(18X*TOTAL VOLUME  :*5X,E10.3,5H M**3)
      RETURN $ END
```

Listing for INVERSI Computer Code

```
      PROGRAM INVERSI(INPUT,OUTPUT,TAPE1,TAPE2)
C
C     THIS IS THE INVERSE INTRUDER AND ACCIDENT CODE.  IT FINDS
C     THE INDIVIDUAL NUCLIDE CONCENTRATIONS NECESSARY TO REACH
C     DOSES ASSIGNED BY THE DLC (DOSE LIMITING CRITERIA).
C
      COMMON/BAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+          /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3)
+               RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6
+          /IMPS/DMY(23,8,14)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
C     DMY(23,8,14) WILL CONTAIN THE CONCENTRATIONS FOR ALL NUCLIDES,
C     7 ORGANS, AND SEVERAL PATHWAYS.
C
      DIMENSION DES(20),ORGAN(8),ISPC(11)
      DATA ORGAN/10H   BODY    ,10H   BONE    ,10H   LIVER   ,10H   THYROID
+             10H  KIDNEY   ,10H    LUNG   ,10H  GI-LLI   ,10H  MINIMUM
      DATA DES/10H UNS1-CON ,10H UNS1-AGR ,10H STA1-CON ,10H STA1-AGR ,
+            10H UNSL-CON ,10H UNSL-AGR ,10H STAL-CON ,10H STAL-AGR ,
+            10H GEN5-CON ,10H GEN5-AGR ,10H HWF1-CON ,10H HWF1-AGR ,
+            10H HWF2-CON ,10H HWF2-AGR ,10H INT-AIR  ,10H ERO-AIR  ,
+            10H INT-WAT  ,10H ERO-WAT  ,10H ACC-CONT ,10H ACC-FIRE /
C
C     THE ABOVE ARRAYS ARE:
C         DES(20)    : DESCRIPTION OF PATHWAYS USED IN BOTH INTRUDER
C                      AND ACCIDENT SCENARIOS.
C         ORGAN(8)   : DESCRIPTION OF 7 ORGANS + A MINIMUM COLUMN.
C         ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
C
      DATA AL240/1.05E-4/
C
C     NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND REGIONAL
C     DATA NECESSARY FOR THIS PROGRAM.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 20 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 10 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   10 CONTINUE
   20 CONTINUE
      DO 30 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+               (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+               (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+               DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   30 CONTINUE
  101 FORMAT(2I5,7F5.2)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4E10.3)
  106 FORMAT(10X,7E10.3)
C
```

Listing for INVERSI Computer Code (continued)

```
C        NEXT, THE 12 DISPOSAL TECHNOLOGY AND 6 SPECTRUM INDICES ARE
C        READ IN THRU INPUT.
C
         READ,IRDC
         READ,(ISPC(J),J=4,9)
         WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
         CALL ZERO(DMY,2576) $ CALL RINV(ISPC,NNUC) $ CALL MIN(DMY,14)
C
C        ABOVE SUBROUTINE RINV WAS CALLED TO CALCULATE CONCENTRATIONS
C        WHICH ARE RETURNED IN DMY MATRIX. SUBROUTINE MIN FINDS
C        SMALLEST CONCENTRATION FOR EACH NUCLIDE - OVER ALL 7 ORGANS.
C
C        LOOP 40 CONSIDERS DAUGHTER IN-GROWTH AND PRINTS OUT INTRUDER
C        CONCENTRATIONS TO TAPE2.
C
         DO 40 K=1,14
         A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
         IF(A1.GT.A2) DMY(17,8,K)=A2
         A1=DMY(17,9,K) $ A2=DMY(23,8,K)*AL240/AL(23)
         IF(A1.GT.A2) DMY(17,8,K)=A2
         A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
         IF(A1.GT.A2) DMY(20,8,K)=A2
         WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
         WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
      40 CONTINUE
         IF(I.NE.-1)GO TO 80
C
C        NEXT SECTION SIMILAR TO ONE ABOVE - ONLY NOW FOR ACCIDENT
C        SCENARIOS.
C
         CALL ZERO(DMY,1840) $ CALL AINV(ISPC,NNUC) $ CALL MIN(DMY,6)
         DO 50 K=1,6
         KK=K+14
         WRITE(2,1003) DES(KK),(ORGAN(J),J=1,8)
         WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
      50 CONTINUE
      80 CONTINUE
    1003 FORMAT(//2X,A9,2X,8A10)
    1004 FORMAT(2X,A10,8E10.2)
    1010 FORMAT(1H1/2X,*DISPOSAL TECHNOLOGY INDICES*/2X
+                   *IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                   *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                   *IH =*I2*  ICL=*I2*  IPO=*I2*  ITC=*I4)
    1020 FORMAT(/2X*SPECTRAL INDICES*/2X
+                   *FLAM  =*I2*   DISP  =*I2/2X
+                   *LEACH =*I2*   CHEM  =*I2/2X
+                   *STABI =*I2*   ACCES =*I2/)
         STOP $ END
C
C
         SUBROUTINE RINV(ISPC,NNUC)
C
C        THIS ROUTINE DOES MOST OF THE WORK IN CALCULATING THE
C        CONCENTRATIONS. IT IS SIMILAR TO SUBROUTINE RCLAIM IN
C        THE OPTIONS CODE EXCEPT THE PATHWAY EQUATIONS HAVE BEEN
C        MODIFIED TO FIND THE CONCENTRATIONS WHEN THE DOSES ARE
C        GIVEN.
```

<u>Listing for INVERSI Computer Code</u> (continued)

```
C
      COMMON/BAST/DCF(23,7,8)/DTIS/FSC(6),FSA(6)/IMPS/DMY(23,8,14)
     +       /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
     +       /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
      DIMENSION EMP(3),ISPC(11),DLC(7)
      DATA EMP/.5,.75,.5/,DLC/2*500.,1500.,3000.,3*1500./
C
C     THE ABOVE ARRAYS ARE:
C         EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
C         ISPC(11)  : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
C         DLC(7)    : DOSE LIMITING CRITERIA FOR 7 ORGANS
C
      I5=ISPC(5) $ I6=ISPC(6) $ I7=ISPC(7)
      I8=ISPC(8) $ I9=ISPC(9) $ NSTB=0
      IF(I8.EQ.1.AND.IS.EQ.1)NSTB=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
      FDES=EMP(IE)*(1.-.9*IG)
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
C
C     OUTSIDE LOOP IN CONCENTRATION CALCULATIONS - SETS UP
C     PARAMETERS NEEDED FOR TESTING WASTE STREAMS AT ALL THREE
C     CLASSIFICATION LEVELS:REGULAR, LAYERED, AND HOT.
C
      DO 50 I3=1,7
      GO TO (11,12,13,14,15,16,17),I3
   11 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   12 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
   13 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
   14 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
   15 GDEL=IPO+500.
      A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   16 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.01 $ A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=0.1*A8C
      A4A=0. $ A8A=0. $ GO TO 20
   17 GDEL=IPO+1000.
      A4C=1. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A8C
      A4A=1. $ A8A=A8C
C
C     MAIN CALCULATION LOOP
C
   20 DO 40 INUC=1,NNUC
      A1=A9*FDES*EXM(AL(INUC)*GDEL)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      B2=A1*A8C*A2*0.057
      B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
```

```
C      B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C      B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
C      B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
       B5=0.25*A1*A8A*A2*0.27
       J=(I3-1)*2 $ A2=B1+B2 $ A3=B3+B4+B5
       IF(A2.NE.0.)DMY(INUC,I,J+1)=DLC(I)/A2
       IF(A3.NE.0.)DMY(INUC,I,J+2)=DLC(I)/A3
C
C      DMY CONTAINS CONCENTRATIONS FOR 2 INTRUDER PATHWAYS
C            (J+1)  : CONSTRUCTION
C            (J+2)  : AGRICULTURE
C
    30 CONTINUE
    40 CONTINUE
    50 CONTINUE
       RETURN $ END
C
C
       SUBROUTINE AINV(ISPC,NNUC)
C
C      THIS ROUTINE PERFORMS FUNCTION SIMILAR TO THE PRECEDING
C      SUBROUTINE - ONLY NOW FOR THE ACCIDENT SCENARIOS.
C
       COMMON/BAST/DCF(23,7,8)/IMPS/DMY(23,8,10)
+             /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+             /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+             /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),
+             TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
       DIMENSION EMP(3),EFF(2),SEFF(2),ISPC(11),
+                DLCEA(7),DLCEW(7),DLCAC(7)
       DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/,
+            DLCEA/7*100./,DLCEW/7*4./,DLCAC/7*500./
C
C      THE ABOVE ARRAYS ARE:
C           EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
C           EFF(2)    : LAND USE VOLUME EFFICIENCIES
C           SEFF(2)   : LAND USE SURFACE AREA EFFICIENCIES
C           ISPC(11)  : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
C           DLCEA(7)  : DOSE LIMITING CRITERIA FOR EROSION AIR
C           DLCEW(7)  : DOSE LIMITING CRITERIA FOR EROSION WATER
C
       GREC=IPO+IIC $ GERO=IPO+2000.
       IF(IC.EQ.2)GERO=IPO+3000.
       IF(IC.EQ.3)GERO=IPO+10000.
       AREA=1.8E3*EMP(IE)/4.0
C      AREA=200.*EMP(IE)*0.012
C      AREA=18.*EMP(IE)/4.0
C      AREA=2.*EMP(IE)*0.012
C      AREA=0.2*EMP(IE)
C
C      NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
C
       FRA=5.72E-5*POP(IR,1)*AREA    $ VUR=EFF(ID)*1.E-6
       FEA=8.09E-6*POP(IR,2)/VUR
       FRW=1.15E-4*POP(IR,3)*AREA
       FEW=1.15E-4*POP(IR,3)/VUR
       I5=ISPC(5) $ A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
       I9=ISPC(9) $ A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
```

Listing for INVERSI Computer Code (continued)

```
C
C     MAIN LOOP FOR EXPOSURE CONCENTRATION CALCULATIONS
C
      DO 20 INUC=1,NNUC
      A6=EXM(GREC*AL(INUC)) $ A7=EXM(GERO*AL(INUC))
      DO 10 IORG=1,7
      F1=FRA*A6*DCF(INUC,IORG,8)*A5*A9 $ F2=FEA*A7*DCF(INUC,IORG,8)
      F3=FRW*A6*DCF(INUC,IORG,7)*A5     $ F4=FEW*A7*DCF(INUC,IORG,7)
      IF(F1.NE.0.) DMY(INUC,IORG,1)=DLCEA(IORG)/F1
      IF(F3.NE.0.) DMY(INUC,IORG,3)=DLCEW(IORG)/F3
      IF(F2.NE.0.) DMY(INUC,IORG,2)=DLCEA(IORG)/F2
      IF(F4.NE.0.) DMY(INUC,IORG,4)=DLCEW(IORG)/F4
   10 CONTINUE
   20 CONTINUE
C
C     NEXT SECTION SETS UP PARAMETERS FOR FIRE(FAF) AND SINGLE
C     CONTAINER(FAS) ACCIDENTS.
C
      FAF=TPO(IR,1) $ FAS=TPO(IR,2)
      I6=ISPC(6) $ IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
      I4=ISPC(4) $ IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
      A9=1. $ I9=ISPC(9) $ IF(I9.GT.1)A9=10.**(1-I9)
      IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
C
C     MAIN LOOP FOR ACCIDENT CONCENTRATION CALCULATIONS
C
      DO 70 INUC=1,NNUC
      DO 70 IORG=1,7
C
      A1=A9*FAS*DCF(INUC,IORG,1)
      A2=A9*FAF*DCF(INUC,IORG,1)
      IF(A1.NE.0.) DMY(INUC,IORG,5)=DLCAC(IORG)/A1
      IF(A2.NE.0.) DMY(INUC,IORG,6)=DLCAC(IORG)/A2
   70 CONTINUE
      RETURN $ END
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
C
      SUBROUTINE MIN(D,N)
      DIMENSION D(23,8,14),X(7)
      DO 10 I=1,23
      DO 10 K=1,N
      DO 5 J=1,7
      X(J)=D(I,J,K)
      IF(X(J).EQ.0.) X(J)=1.E+99
    5 CONTINUE
      D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
   10 CONTINUE
      RETURN $ END
```

Listing for INVERSW Computer Code

```
      PROGRAM INVERSW(INPUT,OUTPUT,TAPE1,TAPE2)
C
C     THIS IS THE INVERSE GROUNDWATER CODE.  IT FINDS INDIVIDUAL
C     NUCLIDE CONCENTRATIONS NECESSARY TO REACH DOSES ASSIGNED IN
C     THE DLC (DOSE LIMITING CRITERIA) STATEMENT.
C
      COMMON/PAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+                 RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DMY(23,8,5)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DMY(23,8,5) WILL CONTAIN THE CONCENTRATIONS OUTPUTED FROM
C     SUBROUTINE GINV.
C
      DIMENSION DES(3),ORGAN(8),ISPC(11),LIM(3),CP(3)
      DATA ORGAN/10H   BODY   ,10H   BONE   ,10H   LIVER  ,10H  THYROID ,
+               10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  ,10H  MINIMUM /
      DATA DES/10H INT-WELL ,10H BOU-WELL ,10H POP-WELL /
      DATA LIM/8H ACTUAL ,8H  LOWER ,8H HIGHER /,CP/1.,.5,4./
C
C     THE ABOVE ARRAYS ARE:
C         DES(3)     : DESCRIPTION OF 3 GROUNDWATER PATHWAYS.
C         ORGAN(8)   : DESCRITION OF 7 ORGAN + A MINIMUM COLUMN.
C         ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
C         LIM(3)     : DESCRIPTION OF 3 RETARDATION LEVELS.
C         CP(3)      : MULTIPLIER USED IN MODIFING RETARDATION LEVEL.
C
      DATA AL240/1.05E-4/
C
C     NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND
C     REGIONAL DATA NECESSARY FOR THIS PROGRAM.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 10 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO  5 K=1,8
    5 READ(1,106)(DCF(I,J,K),J=1,7)
   10 CONTINUE
      DO 15 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+                (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+                (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+                DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   15 CONTINUE
  101 FORMAT(2I5,7F5.2)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4F10.3)
  106 FORMAT(10X,7E10.3)
C
C     REMAINING RETARDATION COEFFICIENTS ARE NOW COMPUTED
C
      DO 20 INUC=1,NNUC
      A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
      RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
   20 RET(INUC,2)=RET(INUC,1)*A1
```

<u>Listing for INVERSW Computer Code</u> (continued)

```
C
C     THE 12 DISPOSAL TECHNOLOGY INDICES AND 6 NECESSARY SPECTRUM
C     INDICES ARE READ IN THRU INPUT.
C
      READ,IRDC $ READ,(ISPC(J),J=4,9)
      WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
C
C     LOOP 35 FINDS THE GROUNDWATER CONCENTRATIONS FOR EACH OF
C     THE 5 RETARDATION COEFFICIENTS. SUBROUTINE GINV DOES MOST OF
C     CALCULATIONS INVOLVED. DAUGHTER IN-GROWTH IS ALSO TAKEN
C     INTO CONSIDERATION.
C
      DO 35 IRET=1,5
      WRITE(2,1005) IRET $ CALL ZERO(DMY,920)
      CALL GINV(ISPC,NNUC,IRET) $ CALL MIN(DMY,3)
      DO 30 K=1,3
      A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
      IF(A1.GT.A2) DMY(20,8,K)=A2
      WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   30 CONTINUE
   35 CONTINUE
C
   40 IR=IRDC(1) $ NR=NRET(IR)
C
C     LOOP 60 FINDS THE GROUNDWATER CONCENTRATIONS FOR THE
C     RETARDATION COEFFICIENT AS IMPLIED BY THE IR INDEX OF
C     DISPOSAL TECHNOLOGY. THIS LOOP HOWEVER VARIES THE PERCOLATION
C     VALUE. IT USES THE VALUE IMPLIED BY IR AS WELL AS HALF THIS
C     VALUE AND DOUBLE THIS VALUE.
C
      DO 60 KN=1,3
      A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
      IF(A1.GT.A2) DMY(20,8,K)=A2
      WRITE(2,1006) LIM(KN) $ CALL ZERO(DMY,920)
      PRC(IR,1)=PRC(IR,1)*CP(KN) $ PRC(IR,2)=PRC(IR,2)*CP(KN)
      CALL GINV(ISPC,NNUC,NR) $ CALL MIN(DMY,3)
      DO 50 K=1,3
      WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   50 CONTINUE
   60 CONTINUE
C
 1001 FORMAT(12I3)
 1003 FORMAT(//2X,A9,8A10)
 1004 FORMAT(A10,8E10.2)
 1005 FORMAT(//2X,*RETARDATION COEFF. *,I2)
 1006 FORMAT(//2X,A7,*PERCOLATION VALUE*)
```

Listing for INVERSW Computer Code (continued)

```
 1010 FORMAT(2X,*DISPOSAL TECHNOLOGY INDICES*/2X,
+               *IR =*,I2,*  ID =*,I2,*  IC =*,I2,*  IX =*,I2/2X,
+               *IE =*,I2,*  IS =*,I2,*  IL =*,I2,*  IG =*,I2/2X,
+               *IH =*,I2,*  ICL=*,I2,*  IPO=*,I2,*  IIC=*,I4)
 1020 FORMAT(/2X,*SPECTRAL INDICES*/2X,
+               *FLAM  =*,I2,*   DISP  =*,I2/2X,
+               *LEACH =*,I2,*   CHEM  =*,I2/2X,
+               *STARI =*,I2,*   ACCES =*,I2)
      STOP $ END
C
C
      SUBROUTINE GINV(ISPC,NNUC,NRT)
C
C     THIS ROUTINE CONTAINS THE ACTUAL CALCULATION OF THE
C     CONCENTRATIONS.
C
      COMMON/RAST/DCF(23,7,8)/IMPS/DMY(23,8,5)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+           /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),
+           TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
      DIMENSION EMP(3),EFF(2),SEFF(2),DLC(7,3),ISPC(11)
      DATA NSEC/10/,DLC/2*500.,1500.,3000.,3*1500.,3*25.,75.,3*25.,7*4./
      DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/
C
C     THE MATRICES AND ARRAYS ABOVE ARE:
C         EMP(3)     : VOLUME EMPLACEMENT EFFICIENCIES
C         EFF(2)     : LAND USE VOLUME EFFICIENCIES
C         SEFF(2)    : LAND USE SURFACE AREA EFFICIENCIES
C         DLC(7,3)   : DOSE LIMITING CRITERIA FOR 7 ORGANS
C                      AND 3 PATHWAYS.
C                      PARTITIONED INTO.
C
      GDEL=0. $ VUR=1.0/(EMP(IE)*EFF(ID))
      IF(IC.EQ.1)PRCD=PRC(IR,1)
      IF(IC.GT.1)PRCD=PRC(IR,2)
      IF(IX.EQ.1)PRCD=4.*PRC(IR,1)
      IF(IX.GT.1)PRCD=2.25*PRCD
      I6=ISPC(6) $ I7=ISPC(7) $ I8=ISPC(8) $ I9=ISPC(9)
      PERC=PRCD $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
      IF(I8.NE.1.OR.IS.NE.1)GO TO 20
      IF(IC.EQ.1)PERC=PRC(IR,1)
      IF(IC.GT.1)PERC=PRC(IR,2)
   20 TVOL=352000.*SQRT(PRC(IR,1)*27.8)
      IF(ID.EQ.2.OR.IH.EQ.1)PERC=PRC(IR,2)/16.
      PERC=PERC*(1.0-0.9*IG)
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I1=NPT $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
      TDUM=1.0/(PERC*VUR*A6*A9) $ IF(I1.LE.0)I1=1
C
```

Listing for INVERSW Computer Code (continued)

```
C     MAIN LOOP - GROUNDWATER PATHWAY EQUATIONS MANIPULATED SO
C                 AS TO FIND CONCENTRATIONS WHEN THE DOSE IS GIVEN.
C
      DO 80 INUC=1,NNUC
      TDUR=TDUM/EMF(INUC)
      DO 70 IPTH=1,3
      I2=6 $ IF(IPTH.EQ.3) I2=7
      B2=BGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC*TDUR)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      A3=0. $ TNRT=RET(INUC,I1)*TTM(IR,IPTH)
      DO 40 ISEC=1,NSEC
      B3=TNRT+RET(INUC,I1)*(ISEC-1)*DTTM(IR)
      IF(B3.GE.TNRT+TDUR)GO TO 50
      A4=ISEC*EXM(AL(INUC)*B3)
      A3=AMAX1(A3,A4)
   40 CONTINUE
   50 DO 60 IORG=1,7
      AD=1.E6*A3*B2*DCF(INUC,IORG,I2)
      A1=0. $ IF(AD.NE.0.) A1=DLC(IORG,IPTH)/AD
   60 DMY(INUC,IORG,IPTH)=A1
   70 CONTINUE
   80 CONTINUE
      RETURN $ END
C
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
C
      SUBROUTINE MIN(D,N)
C
C     THIS ROUTINE RETURNS THE SMALLEST CONCENTRATION - OVER
C     ALL 7 ORGANS - FOR EACH NUCLIDE.
C
      DIMENSION D(23,8,5),X(7)
      DO 10 I=1,23
      DO 10 K=1,N
      DO 5 J=1,7
      X(J)=D(I,J,K)
      IF(X(J).EQ.0.) X(J)=1.E+99
    5 CONTINUE
      D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
   10 CONTINUE
      RETURN $ END
```

Listing of DATA Data File

```
 36   231.000 .120 .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
        1 3.360E-02 2.660E-03 9.740E-05 2.340E-03 2.790E-06 4.530E-03
        1 8.610E-04 8.840E-08 1.940E-04 8.230E-07 2.440E-06 8.230E-07
        1 2.190E-02 4.710E-08 3.710E-07 9.060E-12 2.600E-05 1.820E-05
        1 7.940E-04 3.990E-08 4.154E-05 1.260E-06 9.920E-09 1.380E-05
P-CONCLIQ 1.100E-01 2.435E+05
        2 1.090E-01 3.450E-03 1.270E-04 2.270E-02 2.710E-05 4.400E-02
        2 8.360E-03 8.580E-07 2.520E-04 1.070E-06 3.160E-06 1.070E-06
        2 2.850E-02 6.150E-08 4.840E-07 1.180E-11 5.120E-05 3.310E-05
        2 1.440E-03 7.250E-08 7.132E-05 2.020E-06 1.170E-08 1.920E-05
P-FSLUDGE 1.100E-01 4.279E+03
        3 1.060E+00 2.590E-03 9.550E-05 3.100E-01 3.710E-04 6.000E-01
        3 1.140E-01 1.170E-05 1.890E-04 8.030E-07 2.370E-06 8.030E-07
        3 2.140E-02 1.460E-07 1.150E-06 2.810E-11 4.760E-05 1.550E-04
        3 6.750E-03 3.390E-07 4.581E-04 1.780E-05 3.100E-07 1.770E-04
P-FCARTRG 1.100E-01 2.177E+04
        4 1.860E+00 1.150E-03 4.250E-05 5.550E-01 6.600E-04 1.070E+00
        4 2.040E-01 2.090E-05 8.400E-05 3.580E-07 1.060E-06 3.580E-07
        4 9.540E-03 3.640E-07 2.870E-06 7.020E-11 2.510E-04 3.800E-04
        4 1.660E-02 8.340E-07 6.414E-04 1.100E-05 1.930E-07 1.100E-04
B-IXRESIN 1.200E-01 7.623E+04
        5 4.630E+00 1.920E-02 1.190E-03 9.480E-01 9.800E-04 1.590E+00
        5 2.150E-02 3.090E-05 3.640E-03 7.650E-05 2.040E-04 7.650E-05
        5 2.040E+00 5.330E-08 4.200E-07 1.020E-11 8.340E-05 5.340E-05
        5 2.600E-03 1.170E-07 9.798E-05 1.570E-06 2.700E-08 1.820E-05
B-CONCLIQ 1.200E-01 2.102E+05
        6 2.870E-01 6.240E-04 3.890E-05 7.940E-02 8.210E-05 1.330E-01
        6 1.800E-03 2.590E-06 1.180E-04 2.500E-06 6.650E-06 2.500E-06
        6 6.650E-02 3.440E-08 2.710E-07 6.610E-12 1.990E-04 9.430E-05
        6 4.600E-03 2.060E-07 2.523E-04 8.100E-06 2.590E-07 2.050E-04
B-FSLUDGE 1.200E-01 1.690E+05
        7 5.240E+00 1.260E-02 7.780E-04 1.440E+00 1.490E-03 2.410E+00
        7 3.250E-02 4.700E-05 2.370E-03 5.000E-05 1.330E-04 5.000E-05
        7 1.330E+00 3.320E-07 2.610E-06 6.380E-11 4.660E-04 2.360E-04
        7 1.150E-02 5.180E-07 4.868E-04 1.050E-05 2.970E-07 2.240E-04
P-COTRASH 2.100E-01 4.244E+05
        8 2.280E-02 3.040E-04 1.120E-05 5.970E-03 7.110E-06 1.150E-02
        8 2.190E-03 2.250E-07 2.220E-05 9.420E-08 2.780E-07 9.420E-08
        8 2.510E-03 7.890E-09 6.220E-08 1.520E-12 5.970E-06 5.530E-06
        8 2.410E-04 1.210E-08 1.089E-05 2.670E-07 2.740E-09 2.610E-06
P-NCTRASH 2.100E-01 2.178E+05
        9 5.250E-01 6.990E-03 2.570E-04 1.370E-01 1.640E-04 2.650E-01
        9 5.050E-02 5.180E-06 5.110E-04 2.170E-06 6.410E-06 2.170E-06
        9 5.780E-02 1.820E-07 1.430E-06 3.490E-11 1.380E-04 1.270E-04
        9 5.550E-03 2.790E-07 2.508E-04 6.150E-06 6.300E-08 6.000E-05
B-COTRASH 2.200E-01 2.086E+05
       10 2.350E-02 6.750E-05 4.170E-06 6.010E-03 6.210E-06 1.010E-02
       10 1.360E-04 1.960E-07 1.270E-05 2.680E-07 7.140E-07 2.680E-07
       10 7.140E-03 1.220E-09 9.600E-09 2.350E-13 2.300E-06 1.160E-06
       10 5.630E-05 2.530E-09 2.586E-06 6.520E-08 1.930E-09 1.490E-06
B-NCTRASH 2.200E-01 9.896E+04
       11 3.790E+00 1.090E-02 6.730E-04 9.690E-01 1.000E-03 1.620E+00
       11 2.190E-02 3.160E-05 2.050E-03 4.330E-05 1.150E-04 4.330E-05
       11 1.150E+00 1.970E-07 1.550E-06 3.780E-11 3.710E-04 1.860E-04
       11 9.080E-03 4.080E-07 4.172E-04 1.050E-05 3.120E-07 2.410E-04
F-COTRASH 2.110E-01 2.359E+05
       12 5.580E-06     0.        0.        0.        0.        0.
       12     0.        0.        0.        0.        0.        0.
       12     0.    1.180E-06 4.400E-06     0.        0.        0.
       12     0.        0.        0.        0.        0.        0.
F-NCTRASH 2.110E-01 4.171E+04
       13 5.330E-06     0.        0.        0.        0.        0.
       13     0.        0.        0.        0.        0.        0.
       13     0.    1.130E-06 4.200E-06     0.        0.        0.
       13     0.        0.        0.        0.        0.        0.
```

Listing of DATA Data File (Continued)

--	--	--	--	--	--	--
I-COTRASH	2.030E-01	1.407E+05				
14	1.130E-01	9.130E-02	5.260E-03	0.	0.	1.040E-02
14	0.	0.	1.450E-03	3.390E-09	0.	0.
14	4.560E-03	0.	0.	0.	0.	0.
14	0.	0.	4.820E-06	0.	0.	0.
I+COTRASH	2.030E-01	1.407E+05				
15	1.130E-01	9.130E-02	5.260E-03	0.	0.	1.040E-02
15	0.	0.	1.450E-03	3.390E-09	0.	0.
15	4.560E-03	0.	0.	0.	0.	0.
15	0.	0.	4.820E-06	0.	0.	0.
N-SSTRASH	2.060E-01	1.796E+05				
16	1.120E-05	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.
16	0.	2.360E-06	8.800E-06	0.	0.	0.
16	0.	0.	0.	0.	0.	0.
N+SSTRASH	2.060E-01	1.796E+05				
17	1.120E-05	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.
17	0.	2.360E-06	8.800E-06	0.	0.	0.
17	0.	0.	0.	0.	0.	0.
N-LOTRASH	2.070E-01	5.064E+04				
18	3.530E-02	2.850E-02	1.640E-03	0.	0.	3.250E-03
18	0.	0.	4.530E-04	1.060E-09	0.	0.
18	1.420E-03	0.	0.	0.	0.	0.
18	0.	0.	1.510E-06	0.	0.	0.
N+LOTRASH	2.070E-01	5.064E+04				
19	3.530E-02	2.850E-02	1.640E-03	0.	0.	3.250E-03
19	0.	0.	4.530E-04	1.060E-09	0.	0.
19	1.420E-03	0.	0.	0.	0.	0.
19	0.	0.	1.510E-06	0.	0.	0.
F-PROCESS	3.110E-01	7.816E+04				
20	1.080E-04	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.
20	0.	2.300E-05	8.540E-05	0.	0.	0.
20	0.	0.	0.	0.	0.	0.
U-PROCESS	3.120E-01	2.811E+04				
21	3.800E-04	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.
21	0.	1.650E-05	3.640E-04	0.	0.	0.
21	0.	0.	0.	0.	0.	0.
I-LQSCNVL	3.030E-01	4.914E+04				
22	9.600E-03	5.010E-03	2.510E-04	0.	0.	0.
22	0.	0.	4.340E-03	0.	0.	0.
22	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.
I+LQSCNVL	3.030E-01	4.914E+04				
23	9.600E-03	5.010E-03	2.510E-04	0.	0.	0.
23	0.	0.	4.340E-03	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
I-ABSLIQD	3.030E-01	5.585E+03				
24	1.990E-01	1.420E-01	8.160E-03	0.	0.	3.120E-02
24	0.	0.	4.340E-03	1.020E-08	0.	0.
24	1.370E-02	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.
I+ABSLIQD	3.030E-01	5.585E+03				
25	1.990E-01	1.420E-01	8.160E-03	0.	0.	3.120E-02
25	0.	0.	4.340E-03	1.020E-08	0.	0.
25	1.370E-02	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.
I-BIOWAST	3.030E-01	1.571E+04				
26	2.060E-01	1.750E-01	1.010E-02	0.	0.	3.990E-03
26	0.	0.	8.330E-03	6.510E-09	0.	0.
26	8.760E-03	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.
I+BIOWAST	3.030E-01	1.571E+04				

Listing of DATA Data File (Continued)

```
         27 2.060E-01 1.750E-01 1.010E-02    0.         0.      3.990E-03
         27    0.        0.     8.330E-03 6.510E-09     0.         0.
         27 8.760E-03    0.        0.        0.         0.         0.
         27    0.        0.        0.        0.         0.         0.
N-SSWASTE 3.060E-01 6.339E+04
         28 2.170E-04    0.        0.        0.         0.         0.
         28    0.        0.        0.        0.         0.         0.
         28    0.     4.600E-05 1.710E-04    0.         0.         0.
         28    0.        0.        0.        0.         0.         0.
N-LOWASTE 3.070E-01 6.027E+04
         29 2.110E-02 1.630E-02 9.360E-04    0.         0.      1.470E-03
         29    0.        0.     1.310E-03 7.760E-10     0.         0.
         29 1.040E-03    0.        0.        0.         0.         0.
         29    0.        0.        0.        0.         0.         0.
L-NFRCOMP 4.300E-01 2.887E+03
         30 4.040E+03    0.     2.590E-01 2.230E+03 1.400E+00 1.600E+03
         30 2.090E+02 8.190E-03    0.        0.         0.         0.
         30    0.        0.        0.        0.         0.         0.
         30    0.        0.        0.        0.         0.         0.
L-DECONRS 4.400E-01 3.498E+04
         31 1.560E+02 1.080E-02 6.880E-04 4.050E+01 4.490E-02 7.280E+01
         31 3.690E+00 1.420E-03 4.280E-02 1.200E-05 3.340E-05 1.200E-05
         31 3.180E-01 6.840E-05 5.400E-04 1.320E-08 1.340E+00 1.770E+00
         31 3.550E+01 3.870E-03 1.026E+00 3.590E-04 3.460E-04 3.270E-03
N-ISOPROD 4.040E-01 5.196E+03
         32 1.500E+01 4.200E-02 4.510E-05    0.         0.         0.
         32    0.        0.     6.270E+00 3.270E-04 2.720E-06 3.270E-04
         32 8.730E+00 1.020E-05 3.810E-05 5.330E-13 1.970E-04 5.550E-05
         32 7.100E-03 9.570E-08 2.152E-04 1.250E-06 1.650E-04 2.880E-07
N-HIGHACT 4.030E-01 2.608E+03
         33 2.100E+02    0.     1.320E-02 1.150E+02 6.560E-02 8.480E+01
         33 1.060E+01 4.470E-04    0.        0.         0.         0.
         33    0.        0.        0.        0.         0.         0.
         33    0.        0.        0.        0.         0.         0.
N-TRITIUM 4.050E-01 3.481E+03
         34 2.330E+03 2.330E+03    0.        0.         0.         0.
         34    0.        0.        0.        0.         0.         0.
         34    0.        0.        0.        0.         0.         0.
         34    0.        0.        0.        0.         0.         0.
N-SOURCES 4.030E-01 1.865E+02
         35 5.760E+03 2.090E+03 3.190E-03    0.         0.      8.120E+01
         35 1.050E+01    0.     2.870E+01    0.         0.         0.
         35 3.540E+03    0.        0.        0.         0.         0.
         35    0.        0.     1.600E+01    0.         0.         0.
N-TARGETS 4.030E-01 1.340E+03
         36 8.040E+01 8.040E+01    0.        0.         0.         0.
         36    0.        0.        0.        0.         0.         0.
         36    0.        0.        0.        0.         0.         0.
         36    0.        0.        0.        0.         0.         0.
H-3           5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3     /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3     /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3     /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3     /FOO 5.995E+04    0.     5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3     /DGM    0.        0.        0.        0.        0.        0.        0.
H-3     /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3     /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3     /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14          1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14    /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14    /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14    /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14    /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14    /DGM    0.        0.        0.        0.        0.        0.        0.
C-14    /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14    /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
```

Listing of DATA Data File (Continued)

C-14	/AIR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
FE-55		2.670E-01	1.480E-02	6.300E+02	5.400E+03			
FE-55	/ACC	1.805E+10	1.885E+10	2.413E+10	1.613E+10	1.613E+10	2.081E+11	1.925E+10
FE-55	/CON	9.283E+09	4.816E+10	3.941E+10	5.080E+07	5.080E+07	2.095E+11	2.116E+10
FE-55	/AGR	3.219E+10	1.903E+11	1.376E+11	5.080E+07	5.080E+07	2.644E+11	7.752E+10
FE-55	/FOO	3.482E+01	2.161E+02	1.493E+02	0.	0.	8.331E+01	8.566E+01
FE-55	/DGM	0.	0.	0.	0.	0.	0.	0.
FE-55	/WWT	2.727E+06	1.244E+07	8.863E+06	8.609E+05	8.609E+05	5.326E+06	5.452E+06
FE-55	/SWT	4.450E+06	2.314E+07	1.625E+07	8.609E+05	8.609E+05	9.449E+06	9.692E+06
FE-55	/AIR	4.827E+10	2.064E+11	1.537E+11	1.613E+10	1.613E+10	2.804E+11	9.360E+10
NI-59		8.660E-06	1.480E-02	4.200E+02	3.600E+03			
NI-59	/ACC	3.698E+10	9.378E+10	5.058E+10	2.578E+10	2.578E+10	5.778E+10	2.850E+10
NI-59	/CON	3.872E+10	2.325E+11	8.130E+10	5.980E+07	5.980E+07	3.206E+10	1.441E+10
NI-59	/AGR	1.247E+11	7.476E+11	2.581E+11	5.980E+07	5.980E+07	3.206E+10	5.082E+10
NI-59	/FOO	3.693E+03	2.211E+04	7.590E+03	0.	0.	0.	1.563E+03
NI-59	/DGM	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03
NI-59	/WWT	8.537E+06	4.425E+07	1.609E+07	1.377E+06	1.377E+06	1.377E+06	4.408E+06
NI-59	/SWT	9.825E+06	5.196E+07	1.874E+07	1.377E+06	1.377E+06	1.377E+06	4.953E+06
NI-59	/AIR	1.505E+11	7.733E+11	2.838E+11	2.578E+10	2.578E+10	5.778E+10	7.654E+10
CO-60		1.320E-01	1.480E-02	4.200E+02	3.600E+03			
CO-60	/ACC	2.358E+12	2.336E+12	2.353E+12	2.336E+12	2.336E+12	2.634E+13	2.504E+12
CO-60	/CON	1.237E+11	2.280E+10	7.599E+10	2.280E+10	2.280E+10	2.402E+13	8.593E+11
CO-60	/AGR	3.695E+11	2.280E+10	1.874E+11	2.280E+10	2.280E+10	2.402E+13	2.953E+12
CO-60	/FOO	5.274E+03	0.	2.391E+03	0.	0.	0.	4.492E+04
CO-60	/DGM	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07
CO-60	/WWT	1.432E+08	1.238E+08	1.326E+08	1.238E+08	1.238E+08	1.239E+08	2.893E+08
CO-60	/SWT	1.458E+08	1.238E+08	1.338E+08	1.238E+08	1.238E+08	1.239E+08	3.112E+08
CO-60	/AIR	2.683E+12	2.336E+12	2.500E+12	2.336E+12	2.336E+12	2.634E+13	5.266E+12
NI-63		7.530E-03	1.480E-02	4.200E+02	3.600E+03			
NI-63	/ACC	3.056E+10	9.602E+11	6.576E+10	1.560E+08	1.560E+08	8.816E+10	7.436E+09
NI-63	/CON	1.040E+11	3.150E+12	2.176E+11	1.560E+08	1.560E+08	8.816E+10	3.911E+10
NI-63	/AGR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NI-63	/FOO	9.878E+03	2.945E+05	2.041E+04	0.	0.	0.	4.259E+03
NI-63	/DGM	0.	0.	0.	0.	0.	0.	0.
NI-63	/WWT	1.915E+07	5.711E+08	3.958E+07	4.276E-01	4.276E-01	2.416E+02	8.258E+06
NI-63	/SWT	2.260E+07	6.738E+08	4.670E+07	4.276E-01	4.276E-01	2.416E+02	9.743E+06
NI-63	/AIR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NB-94		3.470E-05	1.110E-02	1.000E+03	1.000E+04			
NB-94	/ACC	6.102E+11	6.114E+11	6.108E+11	6.095E+11	6.107E+11	1.330E+12	6.839E+11
NB-94	/CON	1.389E+10	1.515E+10	1.454E+10	1.320E+10	1.446E+10	7.332E+11	4.432E+11
NB-94	/AGR	1.399E+10	1.548E+10	1.472E+10	1.320E+10	1.464E+10	7.332E+11	1.557E+12
NB-94	/FOO	2.116E+00	7.078E+00	3.937E+00	0.	3.892E+00	0.	2.390E+04
NB-94	/DGM	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06
NB-94	/WWT	3.193E+07	3.196E+07	3.194E+07	3.192E+07	3.194E+07	3.192E+07	1.466E+08
NB-94	/SWT	3.232E+07	3.324E+07	3.266E+07	3.192E+07	3.265E+07	3.192E+07	4.496E+09
NB-94	/AIR	6.103E+11	6.118E+11	6.111E+11	6.095E+11	6.110E+11	1.330E+12	2.153E+12
SR-90		2.470E-02	9.860E-03	9.000E+00	7.300E+01			
SR-90	/ACC	2.417E+13	9.617E+13	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.892E+11
SR-90	/CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90	/AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90	/FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90	/DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90	/WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90	/SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90	/AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99		3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99	/ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99	/CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99	/AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99	/FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99	/DGM	0.	0.	0.	0.	0.	0.	0.
TC-99	/WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99	/SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99	/AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129		4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129	/ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11

Listing of DATA Data File (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E+01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E+01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	9.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04
NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-238/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.840E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.234E+04	7.049E+03	0.	5.393E+03	0.	4.429E+03

Listing of DATA Data File (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PU-239/DGM	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01
PU-239/WWT	7.765E+07	3.172E+09	4.343E+08	3.934E+05	3.285E+08	1.092E+07	2.676E+08
PU-239/SWT	8.286E+07	3.386E+09	4.632E+08	3.934E+05	3.506E+08	1.092E+07	2.858E+08
PU-239/AIR	2.253E+14	4.854E+15	3.127E+15	7.400E+09	9.656E+14	3.840E+15	4.833E+12
PU-241	5.250E-02	4.670E-04	8.400E+02	7.200E+03			
PU-241/ACC	3.040E+12	7.440E+13	4.560E+13	4.780E+07	1.440E+13	6.800E+12	5.568E+09
PU-241/CON	3.046E+12	7.467E+13	4.561E+13	4.780E+07	1.443E+13	6.800E+12	2.861E+10
PU-241/AGR	3.063E+12	7.552E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-241/FOO	2.208E+01	1.097E+03	5.613E+01	0.	1.017E+02	0.	9.310E+01
PU-241/DGM	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01
PU-241/WWT	1.341E+06	6.642E+07	3.512E+06	1.310E-01	6.179E+06	1.864E+04	5.618E+06
PU-241/SWT	1.431E+06	7.091E+07	3.742E+06	1.310E-01	6.596E+06	1.864E+04	5.999E+06
PU-241/AIR	3.063E+12	7.553E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-242	2.480E-06	4.670E-04	8.400E+02	7.200E+03			
PU-242/ACC	2.160E+14	4.480E+15	3.040E+15	1.441E+10	9.601E+14	3.680E+15	2.944E+11
PU-242/CON	2.163E+14	4.492E+15	3.042E+15	6.930E+07	9.613E+14	3.680E+15	1.355E+12
PU-242/AGR	2.173E+14	4.530E+15	3.047E+15	6.930E+07	9.653E+14	3.680E+15	4.722E+12
PU-242/FOO	1.224E+03	4.848E+04	6.783E+03	0.	5.194E+03	0.	4.343E+03
PU-242/DGM	0.	0.	0.	0.	0.	0.	0.
PU-242/WWT	7.520E+07	2.938E+09	4.184E+08	7.674E+05	3.168E+08	1.085E+07	2.628E+08
PU-242/SWT	8.021E+07	3.137E+09	4.462E+08	7.674E+05	3.381E+08	1.085E+07	2.806E+08
PU-242/AIR	2.173E+14	4.530E+15	3.047E+15	1.441E+10	9.654E+14	3.680E+15	4.736E+12
AM-241	1.510E-03	4.110E-03	3.000E+02	2.500E+03			
AM-241/ACC	5.041E+14	7.120E+15	6.640E+15	7.869E+10	3.840E+15	4.241E+14	3.587E+11
AM-241/CON	5.049E+14	7.134E+15	6.645E+15	3.800E+08	3.847E+15	4.240E+14	1.508E+12
AM-241/AGR	5.077E+14	7.176E+15	6.660E+15	3.800E+08	3.868E+15	4.240E+14	5.355E+12
AM-241/FOO	3.599E+04	5.448E+05	1.916E+05	0.	2.707E+05	0.	4.936E+04
AM-241/DGM	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04
AM-241/WWT	2.247E+08	3.340E+09	1.189E+09	4.192E+06	1.663E+09	5.354E+06	3.047E+08
AM-241/SWT	3.721E+08	5.572E+09	1.974E+09	4.192E+06	2.772E+09	5.354E+06	5.069E+08
AM-241/AIR	5.078E+14	7.176E+15	6.660E+15	7.869E+10	3.868E+15	4.241E+14	5.434E+12
AM-243	8.720E-05	4.110E-03	3.000E+02	2.500E+03			
AM-243/ACC	4.961E+14	7.040E+15	6.480E+15	9.096E+10	3.760E+15	4.001E+14	3.630E+11
AM-243/CON	4.969E+14	7.054E+15	6.485E+15	6.090E+08	3.767E+15	4.000E+14	1.713E+12
AM-243/AGR	4.996E+14	7.096E+15	6.499E+15	6.090E+08	3.787E+15	4.000E+14	6.223E+12
AM-243/FOO	3.525E+04	5.441E+05	1.849E+05	0.	2.654E+05	0.	5.787E+04
AM-243/DGM	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05
AM-243/WWT	2.208E+08	3.337E+09	1.148E+09	4.837E+06	1.631E+09	5.933E+06	3.572E+08
AM-243/SWT	3.653E+08	5.566E+09	1.906E+09	4.837E+06	2.718E+09	5.933E+06	5.942E+08
AM-243/AIR	4.997E+14	7.096E+15	6.499E+15	9.096E+10	3.788E+15	4.001E+14	6.313E+12
CM-243	2.170E-02	4.670E-04	3.000E+02	2.500E+03			
CM-243/ACC	3.843E+14	6.161E+15	5.601E+15	2.444E+11	1.760E+15	4.403E+14	5.484E+11
CM-243/CON	3.846E+14	6.171E+15	5.604E+15	2.260E+09	1.763E+15	4.400E+14	1.594E+12
CM-243/AGR	3.866E+14	6.204E+15	5.616E+15	2.260E+09	1.772E+15	4.400E+14	5.629E+12
CM-243/FOO	1.113E+04	1.897E+05	7.155E+04	0.	5.195E+04	0.	2.319E+04
CM-243/DGM	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05
CM-243/WWT	1.647E+08	2.598E+09	9.970E+08	1.296E+07	7.212E+08	1.417E+07	3.269E+08
CM-243/SWT	2.087E+08	3.347E+09	1.280E+09	1.296E+07	9.264E+08	1.417E+07	4.184E+08
CM-243/AIR	3.868E+14	6.204E+15	5.617E+15	2.444E+11	1.772E+15	4.403E+14	5.871E+12
CM-244	3.940E-02	4.670E-04	3.000E+02	2.500E+03			
CM-244/ACC	2.800E+14	4.400E+15	4.160E+15	1.706E+10	1.280E+15	4.400E+14	3.051E+11
CM-244/CON	2.805E+14	4.408E+15	4.163E+15	7.230E+07	1.282E+15	4.400E+14	1.533E+12
CM-244/AGR	2.820E+14	4.433E+15	4.174E+15	7.230E+07	1.289E+15	4.400E+14	5.434E+12
CM-244/FOO	8.520E+03	1.434E+05	6.145E+04	0.	3.978E+04	0.	2.241E+04
CM-244/DGM	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01
CM-244/WWT	1.170E+08	1.954E+09	8.443E+08	9.093E+05	5.430E+08	2.115E+06	3.044E+08
CM-244/SWT	1.507E+08	2.521E+09	1.087E+09	9.093E+05	7.001E+08	2.115E+06	3.929E+08
CM-244/AIR	2.820E+14	4.433E+15	4.174E+15	1.706E+10	1.289E+15	4.400E+14	5.451E+12
REGION 1	9.180E-12	2.960E-11	1.970E-04	4.930E-05	7.700E+03	2.000E+05	4.500E+06
	2.000E+02	5.000E+03	1.000E+04	4.000E+02	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	1.010E-09	1.510E-09	1.120E-07	3
	4.000E+02	8.000E+02	1.830E-10	2.610E-12			
REGION 2	2.010E-11	3.180E-11	1.160E-03	3.240E-05	7.700E+03	2.000E+05	4.500E+06
	4.200E+01	4.000E+02	8.000E+02	1.300E+03	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	3.500E-10	5.250E-10	1.120E-07	3
	6.400E+01	1.600E+03	1.830E-10	3.323E-12			

Listing of DATA Data File (Continued)

REGION 3	2.510E-11	3.280E-11	9.000E-05	2.250E-05	7.770E+03	2.000E+05	4.500E+06
	1.400E+02	2.900E+03	5.800E+03	4.000E+02	1.250E+04	2.500E+04	
	1.000E+00	1.000E+00	1.000E+00	3.860E-10	5.790E-10	1.120E-07	4
	1.600E+02	8.000E+02	1.830E-10	2.550E-12			
REGION 4	2.640E-10	8.060E-11	1.300E-06	3.250E-07	7.700E+03	2.000E+05	4.500E+06
	1.500E+01	3.000E+02	6.000E+02	1.300E+03	3.000E+04	6.000E+04	
	1.000E+00	1.000E+00	1.000E+00	2.660E-11	3.990E-11	1.120E-07	2
	8.000E+00	8.000E+02	1.830E-10	1.790E-12			
REGION 5	2.010E-11	3.180E-11	1.160E-04	3.240E-06	7.700E+03	2.000E+05	4.500E+06
	3.200E+01	3.900E+02	7.900E+02	1.300E+03	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	3.030E-10	4.550E-10	1.120E-07	2
	6.400E+01	1.600E+03	1.830E-10	3.323E-12			
REGION 6	2.010E-11	3.180E-11	1.160E-02	3.240E-04	7.700E+03	2.000E+05	4.500E+06
	9.200E+01	4.500E+02	8.500E+02	1.300E+03	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	3.030E-10	4.550E-10	1.120E-07	4
	6.400E+01	1.600E+03	1.830E-10	3.323E-12			

Listing of DATAD Data File

```
36   231.000 .120  .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
        1 3.360E-02 1.840E-03 9.730E-05 7.300E-04 2.790E-06 2.170E-03
        1 8.150E-04 8.840E-08 1.630E-04 8.230E-07 2.440E-06 8.230E-07
        1 1.860E-02 4.710E-08 3.710E-07 9.060E-12 2.450E-05 1.820E-05
        1 5.630E-04 3.990E-08 4.134E-05 1.260E-06 8.520E-09 1.060E-05
P-CONCLIQ 1.100E-01 2.435E+05
        2 1.090E-01 2.390E-03 1.270E-04 7.080E-03 2.710E-05 2.110E-02
        2 7.920E-03 8.580E-07 2.120E-04 1.070E-06 3.160E-06 1.070E-06
        2 2.430E-02 6.150E-08 4.840E-07 1.180E-11 4.830E-05 3.310E-05
        2 1.020E-03 7.250E-08 7.102E-05 2.020E-06 1.010E-08 1.470E-05
P-FSLUDGE 1.100E-01 4.279E+03
        3 1.060E+00 1.790E-03 9.540E-05 9.670E-02 3.710E-04 2.880E-01
        3 1.080E-01 1.170E-05 1.590E-04 8.030E-07 2.370E-06 8.030E-07
        3 1.820E-02 1.460E-07 1.150E-06 2.810E-11 4.490E-05 1.550E-04
        3 4.790E-03 3.390E-07 4.551E-04 1.780E-05 2.660E-07 1.360E-04
P-FCARTRG 1.100E-01 2.177E+04
        4 1.860E+00 7.970E-04 4.250E-05 1.730E-01 6.600E-04 5.140E-01
        4 1.930E-01 2.090E-05 7.070E-05 3.580E-07 1.060E-06 3.580E-07
        4 8.120E-03 3.640E-07 2.870E-06 7.020E-11 2.370E-04 3.800E-04
        4 1.180E-02 8.340E-07 6.394E-04 1.100E-05 1.660E-07 8.440E-05
B-IXRESIN 1.200E-01 7.623E+04
        5 4.630E+00 1.340E-02 1.190E-03 2.990E-01 9.800E-04 7.700E-01
        5 2.040E-02 3.090E-05 3.080E-03 7.650E-05 2.040E-04 7.650E-05
        5 1.740E+00 5.330E-08 4.200E-07 1.020E-11 7.880E-05 5.340E-05
        5 1.850E-03 1.170E-07 9.768E-05 1.570E-06 2.330E-08 1.400E-05
B-CONCLIQ 1.200E-01 2.102E+05
        6 2.870E-01 4.350E-04 3.890E-05 2.500E-02 8.210E-05 6.440E-02
        6 1.710E-03 2.590E-06 9.970E-05 2.500E-06 6.650E-06 2.500E-06
        6 5.670E-02 3.440E-08 2.710E-07 6.610E-12 1.880E-04 9.430E-05
        6 3.280E-03 2.060E-07 2.513E-04 8.090E-06 2.230E-07 1.580E-04
B-FSLUDGE 1.200E-01 1.690E+05
        7 5.240E+00 8.780E-03 7.770E-04 4.540E-01 1.490E-03 1.170E+00
        7 3.080E-02 4.700E-05 2.000E-03 5.000E-05 1.330E-04 5.000E-05
        7 1.130E+00 3.320E-07 2.610E-06 6.380E-11 4.400E-04 2.360E-04
        7 8.200E-03 5.180E-07 4.848E-04 1.050E-05 2.560E-07 1.720E-04
P-COTRASH 2.100E-01 4.244E+05
        8 2.280E-02 2.110E-04 1.120E-05 1.860E-03 7.110E-06 5.520E-03
        8 2.070E-03 2.250E-07 1.870E-05 9.420E-08 2.780E-07 9.420E-08
        8 2.140E-03 7.890E-09 6.220E-08 1.520E-12 5.640E-06 5.530E-06
        8 1.710E-04 1.210E-08 1.085E-05 2.670E-07 2.350E-09 2.000E-06
P-NCTRASH 2.100E-01 2.178E+05
        9 5.250E-01 4.840E-03 2.570E-04 4.270E-02 1.640E-04 1.270E-01
        9 4.780E-02 5.180E-06 4.300E-04 2.170E-06 6.410E-06 2.170E-06
        9 4.920E-02 1.820E-07 1.430E-06 3.490E-11 1.300E-04 1.270E-04
        9 3.930E-03 2.790E-07 2.498E-04 6.140E-06 5.410E-08 4.600E-05
B-COTRASH 2.200E-01 2.086E+05
       10 2.350E-02 4.700E-05 4.170E-06 1.890E-03 6.210E-06 4.890E-03
       10 1.290E-04 1.960E-07 1.070E-05 2.680E-07 7.140E-07 2.680E-07
       10 6.090E-03 1.220E-09 9.600E-09 2.350E-13 2.170E-06 1.160E-06
       10 4.010E-05 2.530E-09 2.575E-06 6.510E-08 1.660E-09 1.150E-06
B-NCTRASH 2.200E-01 9.896E+04
       11 3.790E+00 7.600E-03 6.720E-04 3.050E-01 1.000E-03 7.840E-01
       11 2.080E-02 3.160E-05 1.730E-03 4.330E-05 1.150E-04 4.330E-05
       11 9.810E-01 1.970E-07 1.550E-06 3.780E-11 3.510E-04 1.860E-04
       11 6.470E-03 4.080E-07 4.152E-04 1.050E-05 2.690E-07 1.860E-04
F-COTRASH 2.110E-01 2.359E+05
       12 5.580E-06    0.        0.        0.        0.        0.
       12    0.        0.        0.        0.        0.        0.
       12    0.     1.180E-06 4.400E-06    0.        0.        0.
       12    0.        0.        0.        0.        0.        0.
F-NCTRASH 2.110E-01 4.171E+04
       13 5.330E-06    0.        0.        0.        0.        0.
       13    0.        0.        0.        0.        0.        0.
       13    0.     1.130E-06 4.200E-06    0.        0.        0.
       13    0.        0.        0.        0.        0.        0.
```

Listing of DATAD Data File (Continued)

--	--	--	--	--	--	--
I-COTRASH	2.030E-01	1.407E+05				
14	1.130E-01	5.950E-02	5.250E-03	0.	0.	4.410E-03
14	0.	0.	1.190E-03	3.390E-09	0.	0.
14	3.780E-03	0.	0.	0.	0.	0.
14	0.	0.	4.760E-06	0.	0.	0.
I+COTRASH	2.030E-01	1.407E+05				
15	1.130E-01	5.950E-02	5.250E-03	0.	0.	4.410E-03
15	0.	0.	1.190E-03	3.390E-09	0.	0.
15	3.780E-03	0.	0.	0.	0.	0.
15	0.	0.	4.760E-06	0.	0.	0.
N-SSTRASH	2.060E-01	1.796E+05				
16	1.120E-05	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.
16	0.	2.360E-06	8.800E-06	0.	0.	0.
16	0.	0.	0.	0.	0.	0.
N+SSTRASH	2.060E-01	1.796E+05				
17	1.120E-05	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.
17	0.	2.360E-06	8.800E-06	0.	0.	0.
17	0.	0.	0.	0.	0.	0.
N-LOTRASH	2.070E-01	5.064E+04				
18	3.530E-02	1.860E-02	1.640E-03	0.	0.	1.380E-03
18	0.	0.	3.710E-04	1.060E-09	0.	0.
18	1.180E-03	0.	0.	0.	0.	0.
18	0.	0.	1.490E-06	0.	0.	0.
N+LOTRASH	2.070E-01	5.064E+04				
19	3.530E-02	1.860E-02	1.640E-03	0.	0.	1.380E-03
19	0.	0.	3.710E-04	1.060E-09	0.	0.
19	1.180E-03	0.	0.	0.	0.	0.
19	0.	0.	1.490E-06	0.	0.	0.
F-PROCESS	3.110E-01	7.816E+04				
20	1.080E-04	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.
20	0.	2.300E-05	8.540E-05	0.	0.	0.
20	0.	0.	0.	0.	0.	0.
U-PROCESS	3.120E-01	2.811E+04				
21	3.800E-04	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.
21	0.	1.650E-05	3.640E-04	0.	0.	0.
21	0.	0.	0.	0.	0.	0.
I-LQSCNVL	3.030E-01	4.914E+04				
22	9.600E-03	3.270E-03	2.510E-04	0.	0.	0.
22	0.	0.	3.550E-03	0.	0.	0.
22	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.
I+LQSCNVL	3.030E-01	4.914E+04				
23	9.600E-03	3.270E-03	2.510E-04	0.	0.	0.
23	0.	0.	3.550E-03	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.
I-ABSLIQD	3.030E-01	5.585E+03				
24	1.990E-01	9.260E-02	8.150E-03	0.	0.	1.320E-02
24	0.	0.	3.550E-03	1.020E-08	0.	0.
24	1.140E-02	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.
I+ABSLIQD	3.030E-01	5.585E+03				
25	1.990E-01	9.260E-02	8.150E-03	0.	0.	1.320E-02
25	0.	0.	3.550E-03	1.020E-08	0.	0.
25	1.140E-02	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.
I-BIOWAST	3.030E-01	1.571E+04				
26	2.060E-01	1.140E-01	1.010E-02	0.	0.	1.690E-03
26	0.	0.	6.820E-03	6.510E-09	0.	0.
26	7.260E-03	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.
I+BIOWAST	3.030E-01	1.571E+04				

Listing of DATAD Data File (Continued)

27	2.060E-01	1.140E-01	1.010E-02	0.	0.	1.690E-03	
27	0.	0.	6.820E-03	6.510E-09	0.	0.	
27	7.260E-03	0.	0.	0.	0.	0.	
27	0.	0.	0.	0.	0.	0.	
N-SSWASTE	3.060E-01	6.339E+04					
28	2.170E-04	0.	0.	0.	0.	0.	
28	0.	0.	0.	0.	0.	0.	
28	0.	4.600E-05	1.710E-04	0.	0.	0.	
28	0.	0.	0.	0.	0.	0.	
N-LOWASTE	3.070E-01	6.027E+04					
29	2.110E-02	1.060E-02	9.350E-04	0.	0.	6.230E-04	
29	0.	0.	1.070E-03	7.760E-10	0.	0.	
29	8.620E-04	0.	0.	0.	0.	0.	
29	0.	0.	0.	0.	0.	0.	
L-NFRCOMP	4.300E-01	2.887E+03					
30	4.040E+03	0.	2.590E-01	6.980E+02	1.400E+00	7.700E+02	
30	1.980E+02	8.190E-03	0.	0.	0.	0.	
30	0.	0.	0.	0.	0.	0.	
30	0.	0.	0.	0.	0.	0.	
L-DECONRS	4.400E-01	3.498E+04					
31	1.560E+02	7.510E-03	6.870E-04	1.270E+01	4.490E-02	3.500E+01	
31	3.490E+00	1.420E-03	3.610E-02	1.200E-05	3.340E-05	1.200E-05	
31	2.710E-01	6.840E-05	5.400E-04	1.320E-08	1.260E+00	1.770E+00	
31	2.520E+01	3.870E-03	1.026E+00	3.590E-04	2.980E-04	2.510E-03	
N-ISOPROD	4.040E-01	5.196E+03					
32	1.500E+01	2.740E-02	4.510E-05	0.	0.	0.	
32	0.	0.	5.140E+00	3.270E-04	2.720E-06	3.270E-04	
32	7.240E+00	1.020E-05	3.810E-05	5.330E-13	1.840E-04	5.550E-05	
32	4.750E-03	9.570E-08	2.151E-04	1.250E-06	1.380E-04	2.110E-07	
N-HIGHACT	4.030E-01	2.608E+03					
33	2.100E+02	0.	1.320E-02	2.970E+01	6.560E-02	3.600E+01	
33	9.950E+00	4.470E-04	0.	0.	0.	0.	
33	0.	0.	0.	0.	0.	0.	
33	0.	0.	0.	0.	0.	0.	
N-TRITIUM	4.050E-01	3.481E+03					
34	2.330E+03	1.520E+03	0.	0.	0.	0.	
34	0.	0.	0.	0.	0.	0.	
34	0.	0.	0.	0.	0.	0.	
34	0.	0.	0.	0.	0.	0.	
N-SOURCES	4.030E-01	1.865E+02					
35	5.760E+03	1.360E+03	3.190E-03	0.	0.	3.440E+01	
35	9.860E+00	0.	2.350E+01	0.	0.	0.	
35	2.930E+03	0.	0.	0.	0.	0.	
35	0.	0.	1.580E+01	0.	0.	0.	
N-TARGETS	4.030E-01	1.340E+03					
36	8.040E+01	5.240E+01	0.	0.	0.	0.	
36	0.	0.	0.	0.	0.	0.	
36	0.	0.	0.	0.	0.	0.	
36	0.	0.	0.	0.	0.	0.	
H-3	5.630E-02	1.150E+00	1.000E+00	1.000E+00			
H-3 /ACC	1.252E+09	5.190E+07	1.252E+09	1.252E+09	1.252E+09	1.252E+09	5.190E+07
H-3 /CON	1.172E+10	5.190E+07	1.172E+10	1.172E+10	1.172E+10	1.172E+10	1.052E+10
H-3 /AGR	4.451E+10	5.190E+07	4.451E+10	4.451E+10	4.451E+10	4.451E+10	4.331E+10
H-3 /FOO	5.995E+04	0.	5.995E+04	5.995E+04	5.995E+04	5.995E+04	5.995E+04
H-3 /DGM	0.	0.	0.	0.	0.	0.	0.
H-3 /WWT	2.367E+06	1.422E-01	2.367E+06	2.367E+06	2.367E+06	2.367E+06	2.367E+06
H-3 /SWT	2.368E+06	1.422E-01	2.368E+06	2.368E+06	2.368E+06	2.368E+06	2.368E+06
H-3 /AIR	4.451E+10	5.190E+07	4.451E+10	4.451E+10	4.451E+10	4.451E+10	4.331E+10
C-14	1.210E-04	5.760E-03	1.000E+01	1.000E+01			
C-14 /ACC	3.166E+09	1.405E+10	3.166E+09	3.166E+09	3.166E+09	3.166E+09	2.526E+09
C-14 /CON	6.678E+10	3.321E+11	6.678E+10	6.678E+10	6.678E+10	6.678E+10	6.614E+10
C-14 /AGR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
C-14 /FOO	3.721E+05	1.861E+06	3.721E+05	3.721E+05	3.721E+05	3.721E+05	3.721E+05
C-14 /DGM	0.	0.	0.	0.	0.	0.	0.
C-14 /WWT	1.441E+07	7.205E+07	1.441E+07	1.441E+07	1.441E+07	1.441E+07	1.441E+07
C-14 /SWT	3.761E+07	1.880E+08	3.761E+07	3.761E+07	3.761E+07	3.761E+07	3.761E+07

Listing of DATAD Data File (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C-14	/AIR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
FE-55		2.670E-01	1.480E-02	6.300E+02	5.400E+03			
FE-55	/ACC	1.805E+10	1.885E+10	2.413E+10	1.613E+10	1.613E+10	2.081E+11	1.925E+10
FE-55	/CON	9.283E+09	4.916E+10	3.941E+10	5.080E+07	5.080E+07	2.095E+11	2.116E+10
FE-55	/AGR	3.219E+10	1.903E+11	1.376E+11	5.080E+07	5.080E+07	2.644E+11	7.752E+10
FE-55	/FOO	3.482E+01	2.161E+02	1.493E+02	0.	0.	8.331E+01	8.566E+01
FE-55	/DGM	0.	0.	0.	0.	0.	0.	0.
FE-55	/WWT	2.727E+06	1.244E+07	8.863E+06	8.609E+05	8.609E+05	5.326E+06	5.452E+06
FE-55	/SWT	4.450E+06	2.314E+07	1.625E+07	8.609E+05	8.609E+05	9.449E+06	9.692E+06
FE-55	/AIR	4.827E+10	2.064E+11	1.537E+11	1.613E+10	1.613E+10	2.804E+11	9.360E+10
NI-59		8.660E-06	1.480E-02	4.200E+02	3.600E+03			
NI-59	/ACC	3.698E+10	9.378E+10	5.058E+10	2.578E+10	2.578E+10	5.778E+10	2.850E+10
NI-59	/CON	3.872E+10	2.325E+11	8.130E+10	5.980E+07	5.980E+07	3.206E+10	1.441E+10
NI-59	/AGR	1.247E+11	7.476E+11	2.581E+11	5.980E+07	5.980E+07	3.206E+10	5.082E+10
NI-59	/FOO	3.693E+03	2.211E+04	7.590E+03	0.	0.	0.	1.563E+03
NI-59	/DGM	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03
NI-59	/WWT	8.537E+06	4.425E+07	1.609E+07	1.377E+06	1.377E+06	1.377E+06	4.408E+06
NI-59	/SWT	9.825E+06	5.196E+07	1.874E+07	1.377E+06	1.377E+06	1.377E+06	4.953E+06
NI-59	/AIR	1.505E+11	7.733E+11	2.838E+11	2.578E+10	2.578E+10	5.778E+10	7.654E+10
CO-60		1.320E-01	1.480E-02	4.200E+02	3.600E+03			
CO-60	/ACC	2.358E+12	2.336E+12	2.353E+12	2.336E+12	2.336E+12	2.634E+13	2.504E+12
CO-60	/CON	1.237E+11	2.280E+10	7.599E+10	2.280E+10	2.280E+10	2.402E+13	8.593E+11
CO-60	/AGR	3.695E+11	2.280E+10	1.874E+11	2.280E+10	2.280E+10	2.402E+13	2.953E+12
CO-60	/FOO	5.274E+03	0.	2.391E+03	0.	0.	0.	4.492E+04
CO-60	/DGM	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07
CO-60	/WWT	1.432E+08	1.239E+08	1.326E+09	1.238E+08	1.238E+08	1.239E+08	2.893E+08
CO-60	/SWT	1.458E+08	1.238E+08	1.338E+08	1.238E+08	1.238E+08	1.239E+08	3.112E+08
CO-60	/AIR	2.683E+12	2.336E+12	2.500E+12	2.336E+12	2.336E+12	2.634E+13	5.266E+12
NI-63		7.530E-03	1.480E-02	4.200E+02	3.600E+03			
NI-63	/ACC	3.056E+10	9.602E+11	6.576E+10	1.560E+08	1.560E+08	8.916E+10	7.436E+09
NI-63	/CON	1.040E+11	3.150E+12	2.176E+11	1.560E+08	1.560E+08	8.816E+10	3.911E+10
NI-63	/AGR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NI-63	/FOO	9.878E+03	2.945E+05	2.041E+04	0.	0.	0.	4.259E+03
NI-63	/DGM	0.	0.	0.	0.	0.	0.	0.
NI-63	/WWT	1.915E+07	5.711E+08	3.958E+07	4.276E-01	4.276E-01	2.416E+02	8.258E+06
NI-63	/SWT	2.260E+07	6.738E+08	4.670E+07	4.276E-01	4.276E-01	2.416E+02	9.743E+06
NI-63	/AIR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NB-94		3.470E-05	1.110E-02	1.000E+03	1.000E+04			
NB-94	/ACC	6.102E+11	6.114E+11	6.108E+11	6.095E+11	6.107E+11	1.330E+12	6.839E+11
NB-94	/CON	1.389E+10	1.515E+10	1.454E+10	1.320E+10	1.446E+10	7.332E+11	4.432E+11
NB-94	/AGR	1.399E+10	1.548E+10	1.472E+10	1.320E+10	1.464E+10	7.332E+11	1.557E+12
NB-94	/FOO	2.116E+00	7.078E+00	3.937E+00	0.	3.892E+00	0.	2.390E+04
NB-94	/DGM	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06
NB-94	/WWT	3.193E+07	3.196E+07	3.194E+07	3.192E+07	3.194E+07	3.192E+07	1.466E+08
NB-94	/SWT	3.232E+07	3.324E+07	3.266E+07	3.192E+07	3.265E+07	3.192E+07	4.496E+09
NB-94	/AIR	6.103E+11	6.118E+11	6.111E+11	6.095E+11	6.110E+11	1.330E+12	2.153E+12
SR-90		2.470E-02	9.860E-03	9.000E+00	7.300E+01			
SR-90	/ACC	2.417E+13	9.617E+13	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.892E+11
SR-90	/CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90	/AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90	/FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90	/DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90	/WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90	/SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90	/AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99		3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99	/ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99	/CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99	/AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99	/FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99	/DGM	0.	0.	0.	0.	0.	0.	0.
TC-99	/WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99	/SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99	/AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129		4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129	/ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11

Listing of DATAD Data File (Continued)

I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E+01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E+01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	8.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04
NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-238/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.840E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.234E+04	7.049E+03	0.	5.393E+03	0.	4.429E+03

Listing of DATAD Data File (Continued)

PU-239/DGM	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01
PU-239/WWT	7.765E+07	3.172E+09	4.343E+08	3.934E+05	3.285E+08	1.092E+07	2.676E+08
PU-239/SWT	8.286E+07	3.386E+09	4.632E+08	3.934E+05	3.506E+08	1.092E+07	2.858E+08
PU-239/AIR	2.253E+14	4.854E+15	3.127E+15	7.400E+09	9.656E+14	3.840E+15	4.833E+12
PU-241	5.250E-02	4.670E-04	8.400E+02	7.200E+03			
PU-241/ACC	3.040E+12	7.440E+13	4.560E+13	4.780E+07	1.440E+13	6.800E+12	5.568E+09
PU-241/CON	3.046E+12	7.467E+13	4.561E+13	4.780E+07	1.443E+13	6.800E+12	2.861E+10
PU-241/AGR	3.063E+12	7.552E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-241/FOO	2.208E+01	1.097E+03	5.613E+01	0.	1.017E+02	0.	9.310E+01
PU-241/DGM	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01
PU-241/WWT	1.341E+06	6.642E+07	3.512E+06	1.310E-01	6.179E+06	1.864E+04	5.618E+06
PU-241/SWT	1.431E+06	7.091E+07	3.742E+06	1.310E-01	6.596E+06	1.864E+04	5.999E+06
PU-241/AIR	3.063E+12	7.553E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-242	2.480E-06	4.670E-04	8.400E+02	7.200E+03			
PU-242/ACC	2.160E+14	4.480E+15	3.040E+15	1.441E+10	9.601E+14	3.680E+15	2.944E+11
PU-242/CON	2.163E+14	4.492E+15	3.042E+15	6.930E+07	9.613E+14	3.690E+15	1.355E+12
PU-242/AGR	2.173E+14	4.530E+15	3.047E+15	6.930E+07	9.653E+14	3.680E+15	4.722E+12
PU-242/FOO	1.224E+03	4.848E+04	6.783E+03	0.	5.194E+03	0.	4.343E+03
PU-242/DGM	0.	0.	0.	0.	0.	0.	0.
PU-242/WWT	7.520E+07	2.938E+09	4.184E+08	7.674E+05	3.168E+08	1.085E+07	2.628E+08
PU-242/SWT	8.021E+07	3.137E+09	4.462E+08	7.674E+05	3.381E+08	1.085E+07	2.806E+08
PU-242/AIR	2.173E+14	4.530E+15	3.047E+15	1.441E+10	9.654E+14	3.680E+15	4.736E+12
AM-241	1.510E-03	4.110E-03	3.000E+02	2.500E+03			
AM-241/ACC	5.041E+14	7.120E+15	6.640E+15	7.869E+10	3.840E+15	4.241E+14	3.587E+11
AM-241/CON	5.049E+14	7.134E+15	6.645E+15	3.800E+08	3.847E+15	4.240E+14	1.508E+12
AM-241/AGR	5.077E+14	7.176E+15	6.660E+15	3.800E+08	3.868E+15	4.240E+14	5.355E+12
AM-241/FOO	3.599E+04	5.448E+05	1.916E+05	0.	2.707E+05	0.	4.936E+04
AM-241/DGM	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04
AM-241/WWT	2.247E+08	3.340E+09	1.189E+09	4.192E+06	1.663E+09	5.354E+06	3.047E+08
AM-241/SWT	3.721E+08	5.572E+09	1.974E+09	4.192E+06	2.772E+09	5.354E+06	5.069E+08
AM-241/AIR	5.078E+14	7.176E+15	6.660E+15	7.869E+10	3.868E+15	4.241E+14	5.434E+12
AM-243	8.720E-05	4.110E-03	3.000E+02	2.500E+03			
AM-243/ACC	4.961E+14	7.040E+15	6.480E+15	9.096E+10	3.760E+15	4.001E+14	3.630E+11
AM-243/CON	4.969E+14	7.054E+15	6.485E+15	6.090E+08	3.767E+15	4.000E+14	1.713E+12
AM-243/AGR	4.996E+14	7.096E+15	6.499E+15	6.090E+08	3.787E+15	4.000E+14	6.223E+12
AM-243/FOO	3.525E+04	5.441E+05	1.849E+05	0.	2.654E+05	0.	5.787E+04
AM-243/DGM	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05
AM-243/WWT	2.208E+08	3.337E+09	1.148E+09	4.837E+06	1.631E+09	5.933E+06	3.572E+08
AM-243/SWT	3.653E+08	5.566E+09	1.906E+09	4.837E+06	2.718E+09	5.933E+06	5.942E+08
AM-243/AIR	4.997E+14	7.096E+15	6.499E+15	9.096E+10	3.788E+15	4.001E+14	6.313E+12
CM-243	2.170E-02	4.670E-04	3.000E+02	2.500E+03			
CM-243/ACC	3.843E+14	6.161E+15	5.601E+15	2.444E+11	1.760E+15	4.403E+14	5.484E+11
CM-243/CON	3.846E+14	6.171E+15	5.604E+15	2.260E+09	1.763E+15	4.400E+14	1.594E+12
CM-243/AGR	3.866E+14	6.204E+15	5.616E+15	2.260E+09	1.772E+15	4.400E+14	5.629E+12
CM-243/FOO	1.113E+04	1.897E+05	7.155E+04	0.	5.195E+04	0.	2.319E+04
CM-243/DGM	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05
CM-243/WWT	1.647E+08	2.598E+09	9.970E+08	1.296E+07	7.212E+08	1.417E+07	3.269E+08
CM-243/SWT	2.087E+08	3.347E+09	1.280E+09	1.296E+07	9.264E+08	1.417E+07	4.184E+08
CM-243/AIR	3.868E+14	6.204E+15	5.617E+15	2.444E+11	1.772E+15	4.403E+14	5.871E+12
CM-244	3.940E-02	4.670E-04	3.000E+02	2.500E+03			
CM-244/ACC	2.800E+14	4.400E+15	4.160E+15	1.706E+10	1.280E+15	4.400E+14	3.051E+11
CM-244/CON	2.805E+14	4.408E+15	4.163E+15	7.230E+07	1.282E+15	4.400E+14	1.533E+12
CM-244/AGR	2.820E+14	4.433E+15	4.174E+15	7.230E+07	1.289E+15	4.400E+14	5.434E+12
CM-244/FOO	8.520E+03	1.434E+05	6.145E+04	0.	3.978E+04	0.	2.241E+04
CM-244/DGM	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01	5.640E+01
CM-244/WWT	1.170E+08	1.954E+09	8.443E+08	9.093E+05	5.430E+08	2.115E+06	3.044E+08
CM-244/SWT	1.507E+08	2.521E+09	1.087E+09	9.093E+05	7.001E+08	2.115E+06	3.929E+08
CM-244/AIR	2.820E+14	4.433E+15	4.174E+15	1.706E+10	1.289E+15	4.400E+14	5.451E+12
REGION 1	9.180E-12	2.960E-11	1.970E-04	4.930E-05	7.700E+03	2.000E+05	4.500E+06
	2.000E+02	5.000E+03	1.000E+04	4.000E+02	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	1.010E-09	1.510E-09	1.120E-07	3
	4.000E+02	8.000E+02	1.830E-10	2.610E-12			
REGION 2	2.010E-11	3.180E-11	1.160E-03	3.240E-05	7.700E+03	2.000E+05	4.500E+06
	4.200E+01	4.000E+02	8.000E+02	1.300E+03	1.000E+04	2.000E+04	
	1.000E+00	1.000E+00	1.000E+00	3.500E-10	5.250E-10	1.120E-07	3
	6.400E+01	1.600E+03	1.830E-10	3.323E-12			

Listing of DATAD Data File (Continued)

```
REGION 3    2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
            1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
            1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07     4
            1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4    2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
            1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
            1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07     2
            8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5    2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
            3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
            1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     2
            6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6    2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
            9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
            1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     4
            6.400E+01 1.600E+03 1.830E-10 3.323E-12
```

Listing of NUCS Data File

36	23	1.00	.12	.06 .03	.06	.12	.06	
H-3		5.630E-02	1.150E+00	1.000E+00	1.000E+00			
H-3	/ACC	1.252E+09	5.190E+07	1.252E+09	1.252E+09	1.252E+09	1.252E+09	5.190E+07
H-3	/CON	1.172E+10	5.190E+07	1.172E+10	1.172E+10	1.172E+10	1.172E+10	1.052E+10
H-3	/AGR	4.451E+10	5.190E+07	4.451E+10	4.451E+10	4.451E+10	4.451E+10	4.331E+10
H-3	/FOO	5.995E+04	0.	5.995E+04	5.995E+04	5.995E+04	5.995E+04	5.995E+04
H-3	/DGM	0.	0.	0.	0.	0.	0.	0.
H-3	/WWT	2.367E+06	1.422E-01	2.367E+06	2.367E+06	2.367E+06	2.367E+06	2.367E+06
H-3	/SWT	2.368E+06	1.422E-01	2.368E+06	2.368E+06	2.368E+06	2.368E+06	2.368E+06
H-3	/AIR	4.451E+10	5.190E+07	4.451E+10	4.451E+10	4.451E+10	4.451E+10	4.331E+10
C-14		1.210E-04	5.760E-03	1.000E+01	1.000E+01			
C-14	/ACC	3.166E+09	1.405E+10	3.166E+09	3.166E+09	3.166E+09	3.166E+09	2.526E+09
C-14	/CON	6.678E+10	3.321E+11	6.678E+10	6.678E+10	6.678E+10	6.678E+10	6.614E+10
C-14	/AGR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
C-14	/FOO	3.721E+05	1.861E+06	3.721E+05	3.721E+05	3.721E+05	3.721E+05	3.721E+05
C-14	/DGM	0.	0.	0.	0.	0.	0.	0.
C-14	/WWT	1.441E+07	7.205E+07	1.441E+07	1.441E+07	1.441E+07	1.441E+07	1.441E+07
C-14	/SWT	3.761E+07	1.880E+08	3.761E+07	3.761E+07	3.761E+07	3.761E+07	3.761E+07
C-14	/AIR	2.660E+11	1.328E+12	2.660E+11	2.660E+11	2.660E+11	2.660E+11	2.654E+11
FE-55		2.670E-01	1.480E-02	6.300E+02	5.400E+03			
FE-55	/ACC	1.805E+10	1.885E+10	2.413E+10	1.613E+10	1.613E+10	2.081E+11	1.925E+10
FE-55	/CON	9.283E+09	4.816E+10	3.941E+10	5.080E+07	5.080E+07	2.095E+11	2.116E+10
FE-55	/AGR	3.219E+10	1.903E+11	1.376E+11	5.080E+07	5.080E+07	2.644E+11	7.752E+10
FE-55	/FOO	3.482E+01	2.161E+02	1.493E+02	0.	0.	8.331E+01	8.566E+01
FE-55	/DGM	0.	0.	0.	0.	0.	0.	0.
FE-55	/WWT	2.727E+06	1.244E+07	8.863E+06	8.609E+05	8.609E+05	5.326E+06	5.452E+06
FE-55	/SWT	4.450E+06	2.314E+07	1.625E+07	8.609E+05	8.609E+05	9.449E+06	9.692E+06
FE-55	/AIR	4.827E+10	2.064E+11	1.537E+11	1.613E+10	1.613E+10	2.804E+11	9.360E+10
NI-59		8.660E-06	1.480E-02	4.200E+02	3.600E+03			
NI-59	/ACC	3.698E+10	9.378E+10	5.058E+10	2.578E+10	2.578E+10	5.778E+10	2.850E+10
NI-59	/CON	3.872E+10	2.325E+11	8.130E+10	5.980E+07	5.980E+07	3.206E+10	1.441E+10
NI-59	/AGR	1.247E+11	7.476E+11	2.581E+11	5.980E+07	5.980E+07	3.206E+10	5.082E+10
NI-59	/FOO	3.693E+03	2.211E+04	7.590E+03	0.	0.	0.	1.563E+03
NI-59	/DGM	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03	6.200E+03
NI-59	/WWT	8.537E+06	4.425E+07	1.609E+07	1.377E+06	1.377E+06	1.377E+06	4.408E+06
NI-59	/SWT	9.825E+06	5.196E+07	1.874E+07	1.377E+06	1.377E+06	1.377E+06	4.953E+06
NI-59	/AIR	1.505E+11	7.733E+11	2.838E+11	2.578E+10	2.578E+10	5.778E+10	7.654E+10
CO-60		1.320E-01	1.480E-02	4.200E+02	3.600E+03			
CO-60	/ACC	2.358E+12	2.336E+12	2.353E+12	2.336E+12	2.336E+12	2.634E+13	2.504E+12
CO-60	/CON	1.237E+11	2.280E+10	7.599E+10	2.280E+10	2.280E+10	2.402E+13	8.593E+11
CO-60	/AGR	3.695E+11	2.280E+10	1.874E+11	2.280E+10	2.280E+10	2.402E+13	2.953E+12
CO-60	/FOO	5.274E+03	0.	2.391E+03	0.	0.	0.	4.492E+04
CO-60	/DGM	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07	1.540E+07
CO-60	/WWT	1.432E+08	1.238E+08	1.326E+08	1.238E+08	1.238E+08	1.239E+08	2.893E+08
CO-60	/SWT	1.458E+08	1.238E+08	1.338E+08	1.238E+08	1.238E+08	1.239E+08	3.112E+08
CO-60	/AIR	2.683E+12	2.336E+12	2.500E+12	2.336E+12	2.336E+12	2.634E+13	5.266E+12
NI-63		7.530E-03	1.480E-02	4.200E+02	3.600E+03			
NI-63	/ACC	3.056E+10	9.602E+11	6.576E+10	1.560E+08	1.560E+08	8.816E+10	7.436E+09
NI-63	/CON	1.040E+11	3.150E+12	2.176E+11	1.560E+08	1.560E+08	8.816E+10	3.911E+10
NI-63	/AGR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NI-63	/FOO	9.878E+03	2.945E+05	2.041E+04	0.	0.	0.	4.259E+03
NI-63	/DGM	0.	0.	0.	0.	0.	0.	0.
NI-63	/WWT	1.915E+07	5.711E+08	3.958E+07	4.276E-01	4.276E-01	2.416E+02	8.258E+06
NI-63	/SWT	2.260E+07	6.738E+08	4.670E+07	4.276E-01	4.276E-01	2.416E+02	9.743E+06
NI-63	/AIR	3.341E+11	1.001E+13	6.931E+11	1.560E+08	1.560E+08	8.816E+10	1.383E+11
NB-94		3.470E-05	1.110E-02	1.000E+03	1.000E+04			
NB-94	/ACC	6.102E+11	6.114E+11	6.108E+11	6.095E+11	6.107E+11	1.330E+12	6.839E+11
NB-94	/CON	1.389E+10	1.515E+10	1.454E+10	1.320E+10	1.446E+10	7.332E+11	4.432E+11
NB-94	/AGR	1.399E+10	1.548E+10	1.472E+10	1.320E+10	1.464E+10	7.332E+11	1.557E+12
NB-94	/FOO	2.116E+00	7.078E+00	3.937E+00	0.	3.892E+00	0.	2.390E+04
NB-94	/DGM	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06	9.630E+06
NB-94	/WWT	3.193E+07	3.196E+07	3.194E+07	3.192E+07	3.194E+07	3.192E+07	1.466E+08
NB-94	/SWT	3.232E+07	3.324E+07	3.266E+07	3.192E+07	3.265E+07	3.192E+07	4.496E+09
NB-94	/AIR	6.103E+11	6.118E+11	6.111E+11	6.095E+11	6.110E+11	1.330E+12	2.153E+12
SR-90		2.470E-02	9.860E-03	9.000E+00	7.300E+01			
SR-90	/ACC	2.417E+13	9.617E+13	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.892E+11

Listing of NUCS Data File (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SR-90 /CON	6.394E+13	2.588E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	4.727E+12
SR-90 /AGR	1.891E+14	7.686E+14	1.760E+09	1.760E+09	1.760E+09	3.296E+10	1.946E+13
SR-90 /FOO	6.407E+07	2.611E+08	0.	0.	0.	0.	7.543E+06
SR-90 /DGM	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04	3.060E+04
SR-90 /WWT	9.564E+09	3.895E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.134E+09
SR-90 /SWT	1.014E+10	4.128E+10	8.835E+06	8.835E+06	8.835E+06	8.835E+06	1.201E+09
SR-90 /AIR	1.892E+14	7.688E+14	1.668E+11	1.668E+11	1.668E+11	1.980E+11	1.962E+13
TC-99	3.270E-06	1.150E-01	2.000E+00	5.000E+00			
TC-99 /ACC	1.176E+09	9.680E+08	2.280E+09	7.600E+08	1.996E+10	7.400E+09	7.880E+09
TC-99 /CON	2.960E+09	5.411E+09	8.890E+09	7.600E+08	1.031E+11	7.962E+09	2.240E+11
TC-99 /AGR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.720E+09	9.008E+11
TC-99 /FOO	6.566E+03	1.635E+04	2.433E+04	0.	3.061E+05	2.067E+03	7.953E+05
TC-99 /DGM	0.	0.	0.	0.	0.	0.	0.
TC-99 /WWT	4.186E+05	1.042E+06	1.551E+06	2.083E+00	1.951E+07	1.318E+05	5.069E+07
TC-99 /SWT	4.240E+05	1.056E+06	1.571E+06	2.083E+00	1.976E+07	1.335E+05	5.135E+07
TC-99 /AIR	8.548E+09	1.933E+10	2.960E+10	7.600E+08	3.636E+11	9.721E+09	9.008E+11
I-129	4.080E-08	1.150E-01	2.000E+00	5.000E+00			
I-129 /ACC	9.139E+11	8.515E+11	8.515E+11	5.128E+13	8.515E+11	8.572E+11	8.521E+11
I-129 /CON	2.068E+12	7.124E+11	6.123E+11	1.624E+15	1.315E+12	6.366E+09	9.787E+10
I-129 /AGR	8.346E+12	2.942E+12	2.528E+12	6.553E+15	5.433E+12	6.366E+09	4.006E+11
I-129 /FOO	6.019E+04	2.137E+04	1.836E+04	4.725E+07	3.947E+04	0.	2.901E+03
I-129 /DGM	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04	1.920E+04
I-129 /WWT	4.289E+07	1.758E+07	1.562E+07	3.081E+10	2.938E+07	3.644E+06	5.536E+06
I-129 /SWT	4.389E+07	1.793E+07	1.592E+07	3.160E+10	3.004E+07	3.644E+06	5.584E+06
I-129 /AIR	9.197E+12	3.792E+12	3.379E+12	6.554E+15	6.284E+12	8.572E+11	1.251E+12
CS-135	2.310E-07	1.620E-04	8.500E+01	7.200E+02			
CS-135/ACC	2.371E+10	9.651E+10	8.851E+10	5.080E+08	3.331E+10	1.491E+10	1.004E+09
CS-135/CON	1.566E+11	4.209E+11	3.879E+11	5.080E+08	1.466E+11	4.884E+10	8.007E+09
CS-135/AGR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-135/FOO	8.836E+03	2.157E+04	1.991E+04	0.	7.531E+03	2.256E+03	4.656E+02
CS-135/DGM	0.	0.	0.	0.	0.	0.	0.
CS-135/WWT	3.318E+07	8.098E+07	7.475E+07	1.392E+00	2.828E+07	8.472E+06	1.748E+06
CS-135/SWT	1.442E+08	3.520E+08	3.250E+08	1.392E+00	1.229E+08	3.683E+07	7.600E+06
CS-135/AIR	5.729E+11	1.437E+12	1.326E+12	5.080E+08	5.014E+11	1.551E+11	2.994E+10
CS-137	2.310E-02	1.620E-04	8.500E+01	7.200E+02			
CS-137/ACC	4.499E+11	6.339E+11	7.779E+11	2.419E+11	4.259E+11	3.299E+11	2.444E+11
CS-137/CON	1.397E+12	1.719E+12	2.351E+12	1.530E+09	8.010E+11	2.941E+11	3.919E+10
CS-137/AGR	5.117E+12	5.872E+12	8.030E+12	1.530E+09	2.729E+12	9.350E+11	1.491E+11
CS-137/FOO	7.896E+04	8.814E+04	1.205E+05	0.	4.092E+04	1.360E+04	2.333E+03
CS-137/DGM	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06	3.500E+06
CS-137/WWT	3.094E+08	3.438E+08	4.655E+08	1.287E+07	1.665E+08	6.394E+07	2.163E+07
CS-137/SWT	1.302E+09	1.452E+09	1.981E+09	1.287E+07	6.808E+08	2.349E+08	5.096E+07
CS-137/AIR	5.358E+12	6.112E+12	8.270E+12	2.419E+11	2.969E+12	1.175E+12	3.895E+11
U-235	9.760E-10	1.250E-04	8.400E+02	7.200E+03			
U-235 /ACC	2.062E+12	3.062E+13	2.214E+11	2.214E+11	7.262E+12	3.360E+15	5.175E+11
U-235 /CON	2.643E+12	4.361E+13	1.590E+09	1.590E+09	1.013E+13	3.360E+15	1.586E+12
U-235 /AGR	5.154E+12	8.500E+13	1.590E+09	1.590E+09	1.979E+13	3.360E+15	5.621E+12
U-235 /FOO	1.443E+04	2.378E+05	0.	0.	5.552E+04	0.	2.319E+04
U-235 /DGM	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05	1.500E+05
U-235 /WWT	2.073E+08	3.235E+09	1.177E+07	1.177E+07	7.643E+08	2.098E+07	3.261E+08
U-235 /SWT	2.109E+08	3.294E+09	1.177E+07	1.177E+07	7.781E+08	2.098E+07	3.318E+08
U-235 /AIR	5.374E+12	8.522E+13	2.214E+11	2.214E+11	2.001E+13	3.360E+15	5.841E+12
U-238	1.540E-10	1.250E-04	8.400E+02	7.200E+03			
U-238 /ACC	1.695E+12	2.882E+13	1.454E+10	1.454E+10	6.575E+12	3.120E+15	2.546E+11
U-238 /CON	2.429E+12	4.145E+13	8.570E+07	8.570E+07	9.447E+12	3.120E+15	1.147E+12
U-238 /AGR	4.774E+12	8.108E+13	8.570E+07	8.570E+07	1.849E+13	3.120E+15	3.989E+12
U-238 /FOO	1.348E+04	2.277E+05	0.	0.	5.196E+04	0.	1.633E+04
U-238 /DGM	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03	5.160E+03
U-238 /WWT	1.835E+08	3.087E+09	7.739E+05	7.739E+05	7.050E+08	9.325E+06	2.221E+08
U-238 /SWT	1.868E+08	3.144E+09	7.739E+05	7.739E+05	7.179E+08	9.325E+06	2.262E+08
U-238 /AIR	4.789E+12	8.109E+13	1.454E+10	1.454E+10	1.850E+13	3.120E+15	4.003E+12
NP-237	3.240E-07	4.670E-04	3.000E+02	2.500E+03			
NP-237/ACC	5.202E+14	1.200E+16	1.120E+15	1.340E+11	3.840E+15	3.602E+14	3.740E+11
NP-237/CON	5.209E+14	1.202E+16	1.122E+15	8.400E+08	3.847E+15	3.600E+14	1.550E+12
NP-237/AGR	5.238E+14	1.209E+16	1.128E+15	8.400E+08	3.868E+15	3.600E+14	5.652E+12
NP-237/FOO	1.645E+04	4.067E+05	3.533E+04	0.	1.223E+05	0.	2.357E+04

Listing of NUCS Data File (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NP-237/DGM	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04	6.560E+04
NP-237/WWT	2.312E+08	5.546E+09	4.885E+08	7.126E+06	1.674E+09	8.113E+06	3.263E+08
NP-237/SWT	2.572E+08	6.189E+09	5.443E+08	7.126E+06	1.867E+09	8.113E+06	3.635E+08
NP-237/AIR	5.239E+14	1.209E+16	1.128E+15	1.340E+11	3.868E+15	3.602E+14	5.785E+12
PU-238	8.020E-03	4.670E-04	8.400E+02	7.200E+03			
PU-238/ACC	2.000E+14	4.080E+15	2.800E+15	1.924E+10	8.801E+14	4.080E+15	3.313E+11
PU-238/CON	2.003E+14	4.091E+15	2.802E+15	8.870E+07	8.812E+14	4.080E+15	1.514E+12
PU-238/AGR	2.012E+14	4.126E+15	2.807E+15	8.870E+07	8.850E+14	4.080E+15	5.277E+12
PU-238/FOO	1.137E+03	4.522E+04	6.371E+03	0.	4.868E+03	0.	4.855E+03
PU-239/DGM	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01	1.930E+01
PU-238/WWT	7.019E+07	2.741E+09	3.931E+08	1.025E+06	2.972E+08	1.221E+07	2.940E+08
PU-238/SWT	7.485E+07	2.926E+09	4.192E+08	1.025E+06	3.171E+08	1.221E+07	3.139E+08
PU-238/AIR	2.012E+14	4.126E+15	2.807E+15	1.924E+10	8.850E+14	4.080E+15	5.297E+12
PU-239	2.840E-05	4.670E-04	8.400E+02	7.200E+03			
PU-239/ACC	2.240E+14	4.800E+15	3.120E+15	7.400E+09	9.601E+14	3.840E+15	3.034E+11
PU-239/CON	2.243E+14	4.813E+15	3.122E+15	5.170E+07	9.613E+14	3.840E+15	1.392E+12
PU-239/AGR	2.253E+14	4.854E+15	3.127E+15	5.170E+07	9.655E+14	3.840E+15	4.826E+12
PU-239/FOO	1.270E+03	5.234E+04	7.049E+03	0.	5.393E+03	0.	4.429E+03
PU-239/DGM	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01	9.390E+01
PU-239/WWT	7.765E+07	3.172E+09	4.343E+08	3.934E+05	3.285E+08	1.092E+07	2.676E+08
PU-239/SWT	8.286E+07	3.386E+09	4.632E+08	3.934E+05	3.506E+08	1.092E+07	2.858E+08
PU-239/AIR	2.253E+14	4.854E+15	3.127E+15	7.400E+09	9.656E+14	3.840E+15	4.833E+12
PU-241	5.250E-02	4.670E-04	8.400E+02	7.200E+03			
PU-241/ACC	3.040E+12	7.440E+13	4.560E+13	4.780E+07	1.440E+13	6.800E+12	5.568E+09
PU-241/CON	3.046E+12	7.467E+13	4.561E+13	4.780E+07	1.443E+13	6.900E+12	2.861E+10
PU-241/AGR	3.063E+12	7.552E+13	4.566E+13	4.780E+07	1.450E+13	6.800E+12	1.008E+11
PU-241/FOO	2.208E+01	1.097E+03	5.613E+01	0.	1.017E+02	0.	9.310E+01
PU-241/DGM	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01	3.430E-01
PU-241/WWT	1.341E+06	6.642E+07	3.512E+06	1.310E-01	6.179E+06	1.864E+04	5.618E+06
PU-241/SWT	1.431E+06	7.091E+07	3.742E+06	1.310E-01	6.596E+06	1.864E+04	5.999E+06
PU-241/AIR	3.063E+12	7.553E+13	4.566E+13	4.780E+07	1.450E+13	6.900E+12	1.008E+11
PU-242	2.480E-06	4.670E-04	8.400E+02	7.200E+03			
PU-242/ACC	2.160E+14	4.480E+15	3.040E+15	1.441E+10	9.601E+14	3.680E+15	2.944E+11
PU-242/CON	2.163E+14	4.492E+15	3.042E+15	6.930E+07	9.613E+14	3.680E+15	1.355E+12
PU-242/AGR	2.173E+14	4.530E+15	3.047E+15	6.930E+07	9.653E+14	3.680E+15	4.722E+12
PU-242/FOO	1.224E+03	4.848E+04	6.783E+03	0.	5.194E+03	0.	4.343E+03
PU-242/DGM	0.	0.	0.	0.	0.	0.	0.
PU-242/WWT	7.520E+07	2.938E+09	4.184E+08	7.674E+05	3.168E+08	1.085E+07	2.628E+08
PU-242/SWT	8.021E+07	3.137E+09	4.462E+08	7.674E+05	3.381E+08	1.085E+07	2.806E+08
PU-242/AIR	2.173E+14	4.530E+15	3.047E+15	1.441E+10	9.654E+14	3.680E+15	4.736E+12
AM-241	1.510E-03	4.110E-03	3.000E+02	2.500E+03			
AM-241/ACC	5.041E+14	7.120E+15	6.640E+15	7.869E+10	3.840E+15	4.241E+14	3.587E+11
AM-241/CON	5.049E+14	7.134E+15	6.645E+15	3.800E+08	3.847E+15	4.240E+14	1.508E+12
AM-241/AGR	5.077E+14	7.176E+15	6.660E+15	3.800E+08	3.868E+15	4.240E+14	5.355E+12
AM-241/FOO	3.599E+04	5.448E+05	1.916E+05	0.	2.707E+05	0.	4.936E+04
AM-241/DGM	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04	7.710E+04
AM-241/WWT	2.247E+08	3.340E+09	1.189E+09	4.192E+06	1.663E+09	5.354E+06	3.047E+08
AM-241/SWT	3.721E+08	5.572E+09	1.974E+09	4.192E+06	2.772E+09	5.354E+06	5.069E+09
AM-241/AIR	5.078E+14	7.176E+15	6.660E+15	7.869E+10	3.868E+15	4.241E+14	5.434E+12
AM-243	8.720E-05	4.110E-03	3.000E+02	2.500E+03			
AM-243/ACC	4.961E+14	7.040E+15	6.480E+15	9.096E+10	3.760E+15	4.001E+14	3.630E+11
AM-243/CON	4.969E+14	7.054E+15	6.485E+15	6.090E+08	3.767E+15	4.000E+14	1.713E+12
AM-243/AGR	4.996E+14	7.096E+15	6.499E+15	6.090E+08	3.787E+15	4.000E+14	6.223E+12
AM-243/FOO	3.525E+04	5.441E+05	1.849E+05	0.	2.654E+05	0.	5.787E+04
AM-243/DGM	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05	1.860E+05
AM-243/WWT	2.208E+08	3.337E+09	1.148E+09	4.837E+06	1.631E+09	5.933E+06	3.572E+08
AM-243/SWT	3.653E+08	5.566E+09	1.906E+09	4.837E+06	2.718E+09	5.933E+06	5.942E+08
AM-243/AIR	4.997E+14	7.096E+15	6.499E+15	9.096E+10	3.788E+15	4.001E+14	6.313E+12
CM-243	2.170E-02	4.670E-04	3.000E+02	2.500E+03			
CM-243/ACC	3.843E+14	6.161E+15	5.601E+15	2.444E+11	1.760E+15	4.403E+14	5.484E+11
CM-243/CON	3.846E+14	6.171E+15	5.604E+15	2.260E+09	1.763E+15	4.400E+14	1.594E+12
CM-243/AGR	3.866E+14	6.204E+15	5.616E+15	2.260E+09	1.772E+15	4.400E+14	5.629E+12
CM-243/FOO	1.113E+04	1.897E+05	7.155E+04	0.	5.195E+04	0.	2.319E+04
CM-243/DGM	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.820E+05	3.920E+05	3.820E+05
CM-243/WWT	1.647E+08	2.598E+09	9.970E+08	1.296E+07	7.212E+08	1.417E+07	3.269E+08
CM-243/SWT	2.087E+08	3.347E+09	1.280E+09	1.296E+07	9.264E+08	1.417E+07	4.184E+08

Listing of NUCS Data File (Continued)

```
[illegible]
CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04    0.     3.978E+04    0.     2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07     3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07     3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07     4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07     2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
```

SPC1 Data File

P-IXRESIN	11	100	100	2	1	1	0	1	1	0010	0
P-CONCLIQ	11	100	140	1	1	2	0	1	1	0110	0
P-FSLUDGE	11	100	100	1	3	1	0	1	1	0010	0
P-FCARTRG	11	100	100	2	2	1	0	0	1	0110	0
B-IXRESIN	11	100	100	2	1	1	0	1	1	0010	0
B-CONCLIQ	11	100	140	1	1	2	0	1	1	0110	0
B-FSLUDGE	11	100	100	1	3	1	0	1	1	0010	0
P-COTRASH	21	100	100	3	2	1	0	0	1	0000	0
P-NCTRASH	51	100	100	0	0	1	0	0	2	0000	0
B-COTRASH	21	100	100	3	2	1	0	0	1	0000	0
B-NCTRASH	51	100	100	0	0	1	0	0	2	0000	0
F-COTRASH	22	100	100	3	2	1	0	0	1	0000	0
F-NCTRASH	22	100	100	0	0	1	0	0	2	0000	0
I-COTRASH	23	100	100	3	2	1	0	0	1	0000	0
I+COTRASH	23	100	100	3	2	1	0	0	1	0000	0
N-SSTRASH	22	100	100	2	2	1	0	0	1	0000	0
N+SSTRASH	22	100	100	2	2	1	0	0	1	0000	0
N-LOTRASH	22	100	100	3	2	1	0	0	1	0000	0
N+LOTRASH	22	100	100	3	2	1	0	0	1	0000	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
I+BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	0	2	0000	0
L-DECONRS	51	100	200	2	0	4	1	1	1	0310	0
N-ISOPROD	51	100	130	1	1	3	1	0	1	0210	0
N-HIGHACT	52	100	100	0	0	1	0	0	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

SPC2 Data File

P-IXRESIN	11	100	165	1	1	3	0	1	1	0210	0
P-CONCLIQ	11	600	182	1	1	3	0	1	1	4210	0
P-FSLUDGE	11	100	165	1	1	3	0	1	1	0210	0
P-FCARTRG	11	100	100	1	1	3	0	1	1	0210	0
B-IXRESIN	11	100	165	1	1	3	0	1	1	0210	0
B-CONCLIQ	11	240	156	1	1	3	0	1	1	4210	0
B-FSLUDGE	11	100	165	1	1	3	0	1	1	0210	0
P-COTRASH	21	200	100	3	2	1	0	0	1	1010	0
P-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
B-COTRASH	21	200	100	3	2	1	0	0	1	1010	0
B-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
F-COTRASH	22	150	100	3	2	1	0	0	1	1010	0
F-NCTRASH	22	100	100	0	0	1	0	0	2	0000	0
I-COTRASH	23	200	100	3	2	1	0	0	1	1010	0
I+COTRASH	23	400	100	3	2	1	0	0	1	2020	0
N-SSTRASH	22	150	100	2	2	1	0	0	1	1010	0
N+SSTRASH	22	300	100	2	2	1	0	0	1	2020	0
N-LOTRASH	22	200	100	3	2	1	0	0	1	1010	0
N+LOTRASH	22	400	100	3	2	1	0	0	1	2020	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	33	128	300	3	3	1	1	1	1	1010	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	33	100	165	3	3	3	0	1	1	0210	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
I+BIOWAST	33	100	192	2	3	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2	0000	0
L-DECONRS	51	100	200	2	0	4	1	1	1	0310	0
N-ISOPROD	51	100	200	1	0	4	1	1	1	0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

SPC3 Date File

P-IXRESIN	11	100	200	2	0	4	0	1	1	0310	0
P-CONCLIQ	11	600	200	2	0	4	0	1	1	4310	0
P-FSLUDGE	11	100	200	1	0	4	0	1	1	0310	0
P-FCARTRG	11	100	100	2	0	4	0	1	1	0310	0
B-IXRESIN	11	100	200	2	0	4	0	1	1	0310	0
B-CONCLIQ	11	240	200	1	0	4	0	1	1	4310	0
B-FSLUDGE	11	100	200	1	0	4	0	1	1	0310	0
P-COTRASH	61	8000	200	0	0	4	0	1	1	6312	0
P-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
B-COTRASH	61	8000	200	0	0	4	0	1	1	6312	0
B-NCTRASH	51	100	100	0	0	1	0	1	2	0000	0
F-COTRASH	62	4000	200	0	0	4	0	1	1	6311	0
F-NCTRASH	22	100	100	0	0	1	0	0	2	0000	0
I-COTRASH	23	2000	200	0	0	4	0	1	1	5311	0
I+COTRASH	23	8000	200	3	0	4	0	1	1	7322	0
N-SSTRASH	22	1000	200	0	0	4	0	1	1	5311	0
N+SSTRASH	22	4000	200	2	0	4	0	1	1	7322	0
N-LOTRASH	22	2000	200	0	0	4	0	1	1	5311	0
N+LOTRASH	22	8000	200	3	0	4	0	1	1	7322	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	33	452	200	0	0	4	0	1	1	5311	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	33	100	200	0	0	4	0	1	1	0310	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	33	1500	200	0	0	4	0	1	1	5311	0
I+BIOWAST	33	100	192	2	0	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	0	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2	0000	0
L-DECONRS	51	1800	200	1	0	4	0	1	1	6312	0
N-ISOPROD	51	100	200	1	0	4	1	1	1	0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

SPC4 Data File

P-IXRESIN	71	1800	200	1	0	4	0	1	1	6312	0
P-CONCLIQ	71	800	200	1	0	4	0	1	1	6312	0
P-FSLUDGE	71	500	200	1	0	4	0	1	1	6312	0
P-FCARTRG	71	100	100	2	0	4	0	1	1	0310	0
B-IXRESIN	71	1800	200	1	0	4	0	1	1	6312	0
B-CONCLIQ	71	640	200	1	0	4	0	1	1	6312	0
B-FSLUDGE	71	500	200	1	0	4	0	1	1	6312	0
P-COTRASH	71	8000	200	1	0	4	0	1	1	6312	0
P-NCTRASH	51	600	100	0	0	1	0	1	2	3010	0
B-COTRASH	71	8000	200	1	0	4	0	1	1	6312	0
B-NCTRASH	51	600	100	0	0	1	0	1	2	3010	0
F-COTRASH	72	4000	200	0	0	4	0	1	1	6311	0
F-NCTRASH	52	600	100	0	0	1	0	1	2	3020	0
I-COTRASH	63	2000	200	0	0	4	0	1	1	5311	0
I+COTRASH	73	8000	200	3	0	4	0	1	1	7322	0
N-SSTRASH	62	1000	200	0	0	4	0	1	1	5311	0
N+SSTRASH	72	4000	200	2	0	4	0	1	1	7322	0
N-LOTRASH	62	2000	200	0	0	4	0	1	1	5311	0
N+LOTRASH	72	8000	200	3	0	4	0	1	1	7322	0
F-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
U-PROCESS	52	100	100	0	3	1	0	1	1	0000	0
I-LQSCNVL	63	452	200	0	0	4	0	1	1	5311	0
I+LQSCNVL	33	100	300	3	3	1	1	0	1	0010	0
I-ABSLIQD	63	10000	200	0	0	4	0	1	1	5311	0
I+ABSLIQD	33	100	300	3	3	1	1	1	1	0010	0
I-BIOWAST	63	1500	200	0	0	4	0	1	1	5311	0
I+BIOWAST	73	100	192	2	0	1	1	0	1	0010	0
N-SSWASTE	31	100	100	0	3	1	0	1	1	0000	0
N-LOWASTE	31	100	100	3	3	1	1	1	1	0000	0
L-NFRCOMP	51	100	100	0	0	1	0	1	2	0000	0
L-DECONRS	71	1800	200	0	0	4	0	1	1	6312	0
N-ISOPROD	51	100	200	1	0	4	1	1	1	0310	0
N-HIGHACT	52	100	100	0	0	1	0	1	3	0000	0
N-TRITIUM	52	100	100	3	3	1	1	1	1	0000	0
N-SOURCES	52	100	100	0	0	1	0	1	2	0000	0
N-TARGETS	52	100	100	0	0	1	0	1	1	0000	0

Appendix I

The following branch technical position on site closure and stabilization is reproduced in its entirety.

UNITED STATES NUCLEAR REGULATORY COMMISSION

BRANCH POSITION - LOW-LEVEL WASTE BURIAL GROUND SITE CLOSURE AND STABILIZATION

Low-Level Waste Branch

Background

Recent events have caused the staff to reassess the terms and conditions of licenses that have been issued under 10 CFR Parts 30, 40, and 70 of NRC's regulations for disposal of materials at low-level waste burial grounds. Licenses do not specifically address measures required to close and stabilize sites when operations cease.

In the past, decommissioning of all types of nuclear facilities was addressed only in general terms, if at all. In recent years, decommissioning of fuel cycle facilities, and particularly stabilization of uranium mill tailings, has been receiving increased regulatory attention. Most licenses for fuel cycle facilities specifically address decommissioning. A Colorado State University report entitled, "Evaluation of Long-Term Stability of Uranium Mill Tailing Disposal Alternatives," was prepared in April 1978. The effectiveness and stability of various engineering designs for the tailings caps, embankments, liners, and water diversion structures were assessed against failure modes such as wind erosion, floods, and settlement. Work such as this, coupled with extensive experience in working out specific methods of uranium mill tailings management, contributes to both a conceptual and technical base for formulating performance objectives for site closure and stabilization for shallow land burial of packaged low-level waste since the activities and engineering are similar in many respects.

The Office of Standards Development, NRC, has a major effort underway to develop criteria and standards for decommissioning of all types of fuel cycle facilities. A comprehensive technical information base is being developed by Battelle's Pacific Northwest Laboratory. Reports on each type of fuel cycle facility are being prepared. A report on decommissioning of low-level waste burial grounds is scheduled to be completed later this spring. Although the report of this work is not completed, information on alternative methodologies, procedures, and costs required for site closure and stabilization has been developed.

The NRC has underway the development of a specific regulatory program for management of LLW. On October 25, 1978, NRC noticed, in the Federal Register, its intent to develop a proposed new 10 CFR Part 61 for LLW and invited advice, recommendations, and comments on the scope of the environmental impact statement for the new part. Site decommissioning is intended to be an integral part of the new regulations, currently scheduled to be published as a proposed rule in late 1980.

Specific events at the Sheffield, Illinois site have, however, necessitated development of an interim Branch Position before these regulatory framework efforts and technical base specific for burial grounds are completed. Towards this end, the NRC staff has developed interim performance objectives for LLW burial ground site closure and stabilization based on information available at this time.

Site closure and stabilization plans developed to meet the objectives outlined below are intended to prepare the site for transfer to a custodial government agency. The custodial agency or agencies will be needed until the site can be released for unrestricted use (usually a few hundred years). The site operator's responsibility and authority for possession of buried wastes continues until the Commission finds that the plan established for preparation of the site for transfer to another person has been satisfactorily completed in a manner to reasonably assure protection of the public health and safety and takes action to terminate responsibility and authority under their license.

Position

The staff recognizes that the site closure and stabilization program required at a site will vary depending on site or region specific parameters, such as geology, hydrology, and climate as well as arrangements that may have been concluded between the licensee and site owner. The operating history of the burial ground, site performance as shown by maintenance and monitoring programs, site inventories, and anticipated future use of the site will also be important factors. The overall objective is to leave the site in a condition such that the need for active ongoing maintenance is eliminated and only passive surveillance and monitoring are required at the point when the license is terminated.

Low-level waste burial ground licensees shall develop a site closure and stabilization plan that addressess, as a minimum, the following performance objectives.

1. Bury all waste in accordance with the requirements of the license.

2. Dismantle and decontaminate as required and dispose of all structures, equipment, and materials that are not to be transferred to the custodial agency.

3. Document the arrangements and the status of the arrangements for orderly transfer of site control and for long-term care by the government custodian. Also document the agreement, if any, of state or federal government participation in, or accomplishment of, any performance objective. Specific funding arrangements to assure the availability of funds to complete the site closure and stabilization plan must be made.

4. Direct gamma radiation from buried wastes should be essentially background.

5. Demonstrate that the rate of release of radionuclides through air and ground and surface water pathways are at or below acceptable levels. Acceptable levels for water are those set forth in 10 CFR Part 20, Appendix B, at the site boundry and EPA drinking water limits at the nearest water supply. Acceptable levels for air are a small fraction of those in 10 CFR Part 20, Appendix B. The EPA environmental standard for disposal of low-level wastes should be used when available.

6. Render the site suitable for surface activities during custodial care. Planned custodial care may be limited to activities such as vegetation control, minor maintenance, and environmental monitoring. However, use of the site surface for activities such as parking lots may be planned. Final conditions at the site must be acceptable to the custodial agency and compatable with its plans for the site.

7. Demonstrate that all trench bottom elevations are above water table levels taking into account the complete history of seasonal fluctuations.

8. Eliminate the potential for erosion or loss of site or trench integrity due to factors such as ground water, surface water, wind, subsidence, and frost action. For example, an overall site surface water management system must be established for humid sites to drain rainwater and snowmelt away from the burial trenches. All slopes must be sufficiently gentle to prevent slumping or gullying. The surface must be stabilized with established short-rooted grass, rock, riprap, or other measures. Trench caps must be stabilized so that erosion, settling, or slumping of caps does not occur.

9. Demonstrate that trench markers are in place, stable, and keyed to benchmarks. Identifying information must be clearly and permanently marked.

10. Compile and transfer to the custodial agency complete records of site maintenance and stabilization activities, trench elevation and locations (in USGS coordinates), trench inventories, and monitoring data for use during custodial care for unexpected corrective measures and data interpretation.

11. Establish a buffer zone surrounding the site sufficient to provide space to stabilize slopes, incorporate surface water management features, assure that future excavations on adjoining areas would not compromise trench or site integrity, and provide working space for unexpected mitigating measures in the future. The buffer zone must also be transferred to the custodial agency. The width of the buffer zone will be determined on a site-specific basis. The buffer zone may generally be less than 300 feet.

12. Provide a secure passive site security system (e.g., a fence) that requires minimum maintenance.

13. Stabilize the site in a manner to minimize environmental monitoring requirements for the long-term custodial phase and develop a monitoring program based on the stabilization plan for implementation by the custodial agency.

14. Investigate the causes of any statistical increases in environmental samples which have occurred during operation and stabilization. In particular, any evidence of unusual or unexpected rates or levels of radionuclide migration in or with the ground water must be analyzed and corrective measures implemented.

15. Eliminate the need for active water management measures, such as sump or trench pumping and treatment of the water to assure that wastes are not leached by standing water in the trenches. Passive systems are preferred. Engineered methods of intercepting contaminated ground water or diverting ground water should also be passive.

16. Evaluate present and zoned activities on adjoining areas to determine their impact on the long-term performance of the site and take reasonable action to minimize the effects. Staff recognizes that these actions would normally be limited to areas under control of the licensee.

Implementation

All objectives will be considered and satisfied to the extent practicable during the review of requests for burial ground operating license termination. Existing licenses will be amended to add conditions requiring submittal of site closure and stabilization plans and explicit requirements for satisfactory completion of the plan before the license can be terminated and the material buried at the site transferred to custodial government care. New applicants will be required to submit preliminary site closure and stabilization plans as part of the initial application.

Appendix J

REGIONAL CASE STUDIES

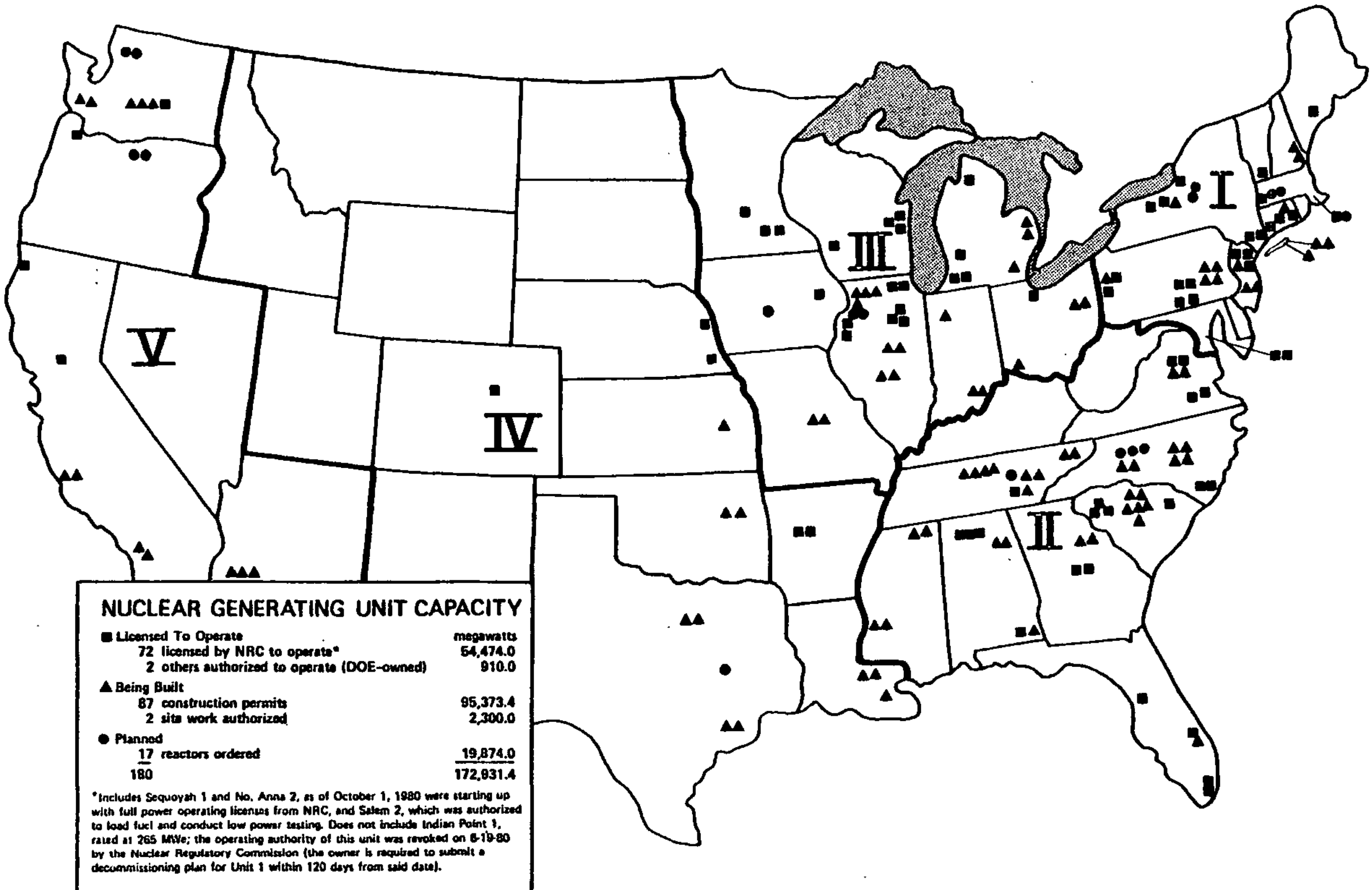
This appendix presents the results of four regional case studies. Each regional case study consists of the calculation of impact measures for a geographic region of the conterminous United States resulting from the disposal of low-level radioactive waste (LLW) generated and disposed within that region for a period of 20 years. The regional case studies are meant to help provide an illustration of the unmitigated impacts of LLW disposal on a regional basis following the application of the performance objectives and technical criteria for LLW disposal established in this environmental impact statement.

In this appendix, the conterminous U.S. has been divided into four regions with boundaries based upon those for the U.S. NRC Regions, shown in Figure J.1. These waste generating regions will be referred to in this appendix as the northeast (Region 1), southeast (Region II), midwest (Region III), and western regions (Regions IV and V). Each of these regions are projected to generate up to one million m^3 of LLW between the years 1980 and 2000 (see Appendix D).

Within each region a hypothetical disposal facility is assumed to be located at a site which is consistent with: (a) the basic disposal facility siting considerations discussed in Chapters 4 and 5 and Appendix E, and (b) the generic environmental characteristics within that geographical region. These regional sites are described in Section 1. A description of the disposal facilities assumed to be situated at each of these sites are presented in Section 2. The design, operation, and closure of these hypothetical disposal facilities are consistent with the performance objectives and the technical criteria outlined in this environmental impact statement. Finally, the various quantifiable impact measures associated with the management and disposal of LLW generated within that region at each of these regional disposal facilities are outlined and compared in Section 3.

1. REGIONAL SITE DESCRIPTIONS

This section provides a brief description of the hypothetical sites utilized for the regional case studies. These hypothetical sites are meant to be consistent with the basic siting considerations presented in Chapters 4 and 5, Appendix E, and the generic environmental characteristics within the region in which the site is assumed to be located. The regional site descriptions are meant to be typical of the environmental characteristics of the regions and have been developed from a number of sources. The regional site descriptions are intended to describe reasonable sites--i.e., sites that could be licensed--but are not intended to represent the "best" site that could be located within a region. The site descriptions should not be interpreted as representing any existing disposal facility or specific location within the regions. Neither should they be interpreted as NRC advocacy of any region or any specific location or site within a region.



BECAUSE OF SPACE LIMITATIONS, SYMBOLS DO NOT REFLECT PRECISE LOCATIONS

Figure J.1 U.S. NRC Regions

1.1 Northeastern Site

The northeastern site is assumed to be located within the Appalachian Upland portion of the Appalachian Plateau physiographic province. A general topographic map of the site is presented in Figure J.2.

The area has been reworked by erosional and depositional forces associated with glacial and postglacial activities. The disposal facility site is on an upland area, having an average elevation of about 555 m (1,820 ft) above mean sea level (msl), and slopes to the south at a rate of about 3%. The drainage from the site flows into the headwaters of Point Creek.

1.1.1 Geology

Throughout most of the Appalachian Upland, the bedrock is underlain by unconsolidated deposits of glacial origin. The thickness of these units is generally greater in the lowlands and valleys, gradually thinning out over the upland regions. The material properties of the deposits are highly variable.

The site is underlain by approximately 9 to 23 m (30 to 75 ft) of compact glacial till frequently referred to as hardpan. Thin and discontinuous interbedded layers of sand and gravel are observed locally in the area. Coarser-grained sediments are principally found in valleys and lowlands, and are associated with stream channels.

Underlying the glacial mantle are flat lying rocks of upper Devonian Age belonging to the Schaffer Group. These rocks consist of marine, black, and gray shales and siltstones, with some thin sandstone layers. The regional dip of the strata is to the south-southwest at a rate of about 2%. A west-northwest/east-southeast geologic profile of the site area is shown on Figure J-3.

The northeast site falls within one of the more tectonically stable regions of the northeast. The site location has been estimated to have a peak horizontal ground acceleration of 0.04 g, with a recurrence interval of more than 500 years. Based on available data, no capable faults are known to underlie the site or lie within 5 miles of the site.

1.1.2 Soils

The site area is covered by silty loams with an underlying brittle, dense fragipan. The predominant soil types belong to the Brickton, Warren, Chitta and Highland series. The parent material consists of acidic, low lime content, dense glacial till.

The site has slopes ranging from nearly level to moderately rolling grades, and the runoff potentials are correspondingly variable. The soils are deep and generally poorly drained. Permeabilities for the uppermost foot of soils are moderate, ranging from 15 to 50 mm per hour (0.6 to 2 inches per hour). However, the dense silty fragipan subsoil is of considerable thickness and is highly impervious, affording low permeabilities ranging between less than 1.5 to 5 mm (0.06 and 0.2 inches) per hour. The soil is strongly acidic, especially

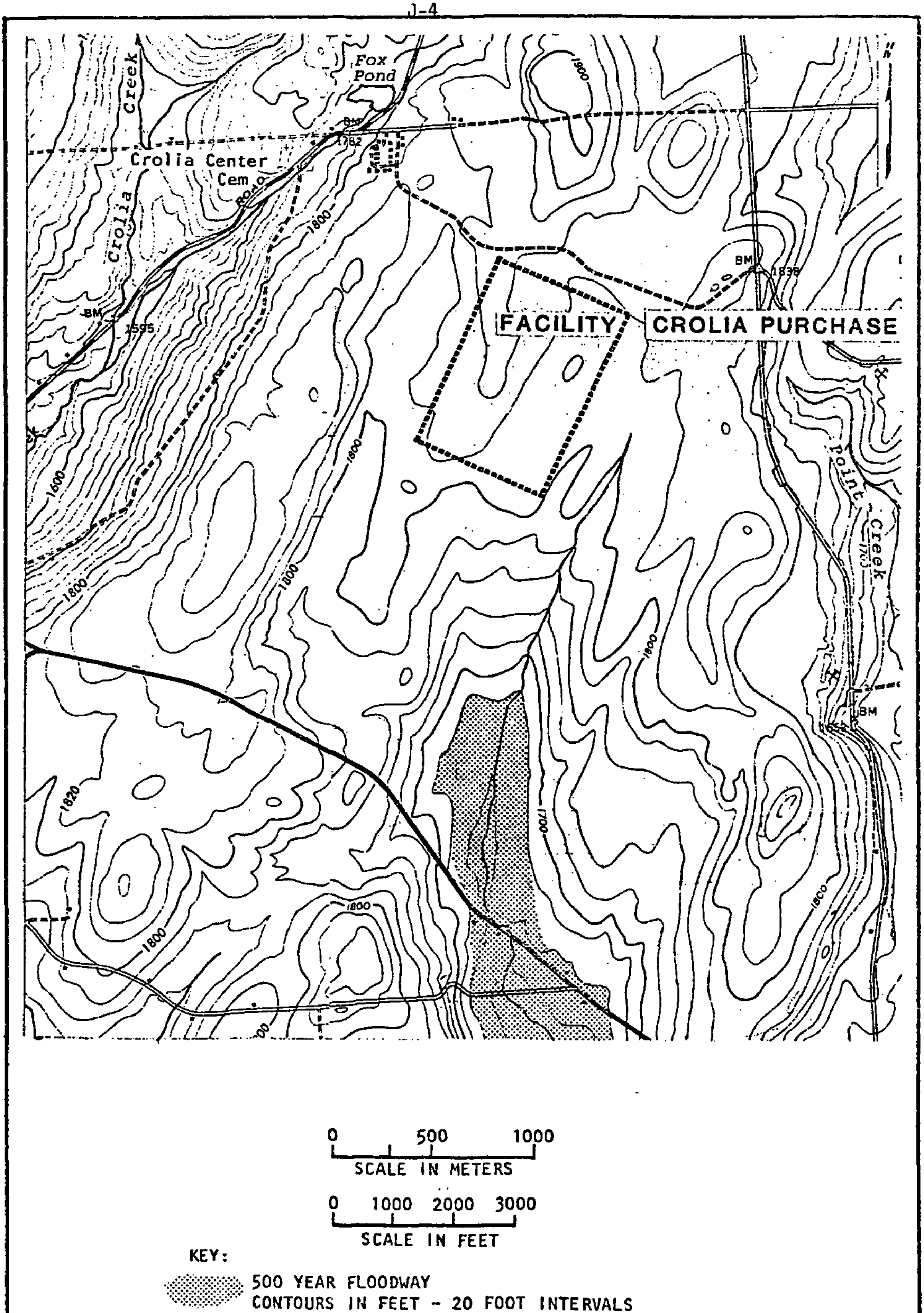


Figure J.2 Northeast Site

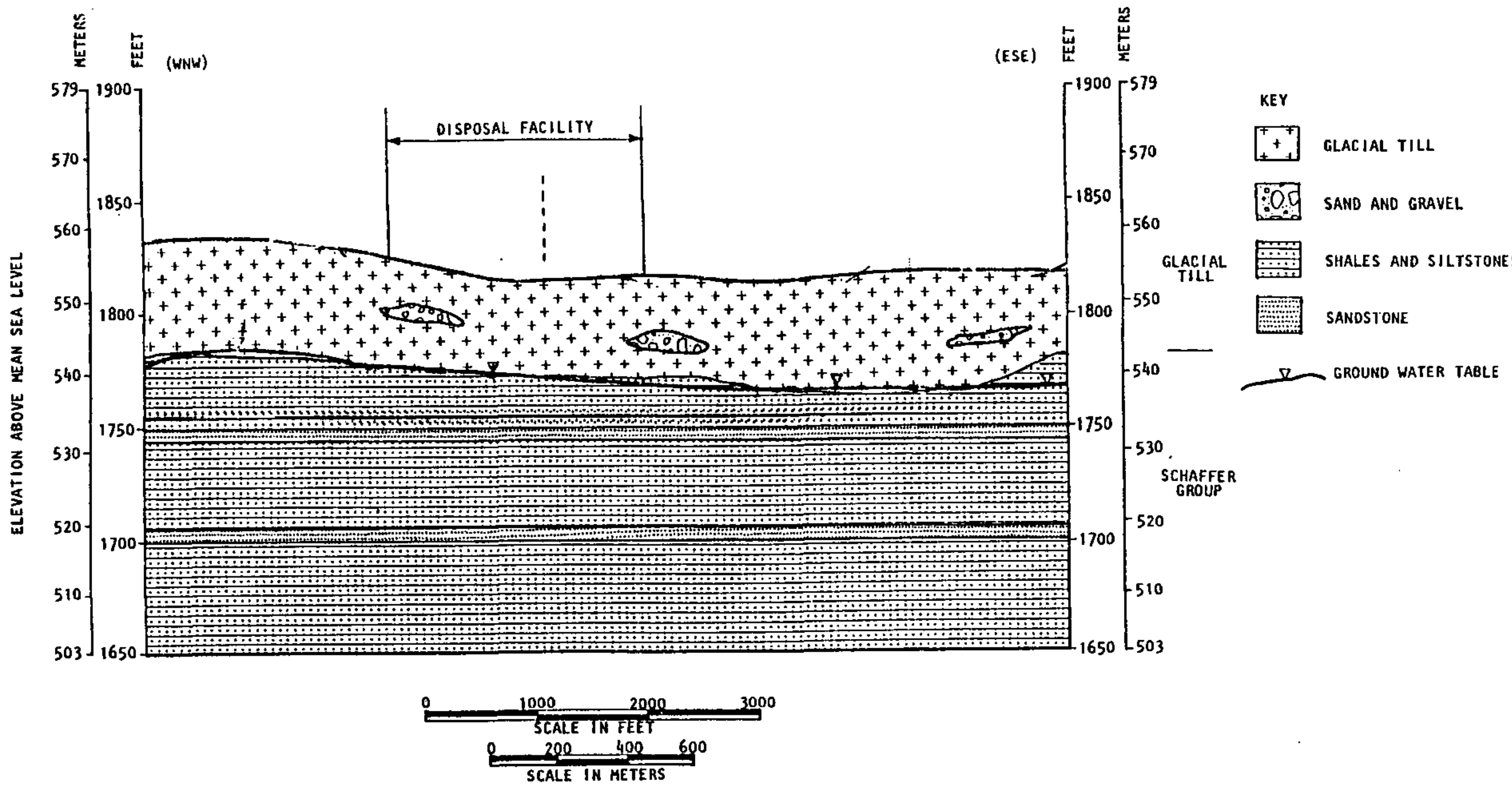


Figure J.3 Geologic Profile of the Northeast Site in the topsoil layer. The plentiful root material in the upper layers contribute to the relatively high organic matter composition. In general, available nitrogen is high, with a moderate phosphorus and potassium content. The low lime content of the glacial till might indicate a correspondingly low calcium content.

1.1.3 Ground Water

The ground water generally occurs where the bedrock and glacial till meet. The depth to ground water at the site averages about 12 meters. The amount of ground water available in the local upland area in which the site is located is largely limited to that which reaches the zone of saturation from precipitation falling upgradient of the site. This recharge quantity is small because of the low permeability of the till, and the heavily vegetated nature of the land surface which acts to hold water in the surficial organic matter affording greater loss via evapotranspiration. Recharge in these areas is limited, ranging from 5 to 50 mm (0.2 to 2.0 inches) per year.

Ground water occurrence in the bedrock is limited to secondary openings along fracture zones and bedding planes. Generally, the fine-grained character associated with the shales and siltstones inhibits water movement. Rocks of this type typically have an upper permeability of about 4.72×10^{-7} to 4.72×10^{-5} cm/sec (0.01 to 1.0 gallons/day/ft^2 (gpd/ft^2)). Movement in the intergranular pore spaces of the sandstone layers will be somewhat greater.

Ground water flow is to the south, following the local topography, and enters the unconsolidated deposits at erosional interfaces. As stated previously, till is not a good water-bearing unit. The permeability of this material is on the order of 4.72×10^{-8} to 4.72×10^{-9} cm/sec (0.001 to 0.0001 gpd/ft^2). here coarse-grained deposits are encountered, the permeability increases considerably, with values ranging from 4.72×10^{-2} to 4.72 cm/sec (1,000 to 10,000 gpd/ft^2). Most of the recharge entering at the site follows the hydraulic gradient to the south and is discharged as base flow into the headwaters of Point Creek which is about 1,000 m (3,000 ft) away.

Ground-water usage in this rural setting is very low. Pumpage is limited to widely scattered wells serving as domestic supplies to local homes and farmsteads. Most of these rural supplies are obtained from bedrock wells, 30 to 61 m (100 to 200 ft) in depth, although some of the water comes from seepage from the overlying deposits around the well casings. The average yields range between 23 to 30 liters per minute (6 to 10 gpm).

The quality of ground water in the unconsolidated deposits and upper shale units is generally good. Occasional samples collected in the upper shales were found to be high in total dissolved solids and hardness; however, average values are relatively low. Water in the unconsolidated deposits tends to reflect the influence of the underlying bedrock. In general, water from the deep gravel deposits is high in iron, and water from shallow gravel deposits is very hard.

1.1.4 Surface Water

The site is located in the once glaciated region of the Brokill Mountains. The rolling terrain is typical of the region, the result of glacial scour and fill. The drainage basin in which the site is located covers 7.36 km^2, with a coarse drainage density of 0.5 (dimensionless). Total stream length above the site is 2,286 m (7,500 ft).

The site vicinity is generally sloping to the south with total vegetative cover. The surface soils and vegetation allow for considerable retention of precipitation; only 20 to 30 percent of precipitation becomes surface runoff. A strong correlation exists between stream discharge and precipitation in the basin. Mean annual discharge at the outlet of the basin is 0.99 m^3/s (35 cfs), but a wide variation in flow occurs throughout the year. Analysis of the unit hydrograph indicates that while peak discharge in the stream occurs within 30 minutes of rainfall commencement, recession of the flow takes up to 30 hours. This variation is likely due to the base flow sustained by and fair weather runoff derived from ground water.

Saturation of the lower basin area occurs during high intensity precipitation events, causing return flow. The maximum discharge of a 500 year flow is estimated to be on the order of 368 m^3/s (13,000 cfs). The floodway of such a flow is delineated on Figure J-2. As can be seen, the site is located well above the floodway.

Development of the site will tend to reduce the infiltration area of the basin, reduce the time to peak discharge and increase the flood stage of the stream. Facility operations such as placement of impervious cover materials and clearing of vegetation are expected to increase the runoff by approximately 60% by the time the facility is closed. This increased runoff, however, will not result in increased potential for site flooding.

1.1.5 Meteorology

The climate in the area of the northeastern site is classified as humid continental, characterized by wide variations in seasonal precipitation and temperature. Moisture sources for precipitation are obtained from the southerly flow of Gulf air during the summer, cyclones that originate in the Great Lakes, and Atlantic Coast systems. Precipitation is uniformly distributed over the year with the greatest average monthly amounts occuring during April through September in the form of thunder showers. The average annual precipitation is approximately 1,034 mm (41 in).

The area is characterized by distinct seasonal temperature variations. Winters are predominantly cold with maximum temperatures ranging from 0 to 20°C (32 to 68°F), and nightime minimums of from -9 to -7°C (15 to 20°F). The temperatures are generally mild during June through August and maximum temperatures average from 24 to 26°C (75-79°F). The mean annual temperature for the area is 8°C (46.0°F).

The prevailing wind direction is southerly from May through November and westerly during the winter and early spring. The average wind speeds during these periods are 15.6 and 17.8 km/hr (8.4 and 9.6 knots), respectively. The average annual windspeed near the site is 16.6 km/hr (10.3 mph), and occurs from the west-southwest direction. Thunderstorms occur on an average of about 30 days per year and are more vigorous during the warm season. Tornados are not common but may occur between late May and late August. Freezing rain storms generally occur on one or more occasions during the winter but are of short duration.

Since the area is characterized by frequent storm passages, particularly from late fall to early spring, relatively low frequencies of nocturnal solar radiation occur. Northwest winds blowing over the western slopes of the nearby mountains during winter also enhance the instability of the area climate. Inversions based below 152 m (500 ft) above the surface may be expected to occur 20 to 30 percent of the time in any season. As a result, mixing heights and wind speeds have less variations

1.1.6 <u>Terrestrial Ecology</u>

The site is located within the Appalachian Highland Division of the Hemlock-White Pine-Northern Hardwoods Region. The region is characterized by pronounced alternating presence of decidious, coniferous, and mixed forest communities. Approximately half of the county in which the site is located is currently used for agriculture, with much of the remaining area covered by secondary forest growth. Public use areas within a 40 km (25 mi) radius of the site include the Crolia Wildlife Management Area located 2.7 km (1.7 mi) north, the Crown Lake State Park located 9.7 km (6 mi) south, the Frog Pond State Park located 29 km (18 mi) east, and the Severn Fish Hatchery located 6.4 km (4 mi) northwest.

The disposal facility site itself is entirely forested. The dominant species are sugar maple, American beech, yellow birch, hemlock and white pine. The immediate vicinity of facility is also forested to a great extent, continuous with the woodlands found onsite.

No state or federally declared rare or endangered species are known to occur onsite. A variety of mammal species are found onsite. The most abundant are small mammals such as the white footed mouse, short-tailed shrew, woodland jumping mice, and meadow mole. Common medium sized mammals are woodchuck, opossum, and gray squirrel. White-tailed deer are also abundant in this area.

Most mammals utilizing the site, with the exception of woodchucks, are not burrowing species. These mammals dig tunnels which average 1.2 to 1.5 meters (4 to 5 ft) deep, and 7.6 to 9.2 meters (25 to 30 ft) long. Home ranges of the common mammals vary depending upon the availability of food.

A moderate number of reptiles have been observed or are expected to occur within the deciduous woodlands. Reptiles found include the eastern garter snake and snapping turtle, the latter being essentially restricted to areas immediately adjacent to water. Other reptiles observed include the spotted salamander, the wood frog, and the American toad.

1.1.7 Aquatic Ecology

The aquatic environment near the site is limited to Point Creek (2 mi from the site to the east) and its tributary, Boyle Creek (1 mi from the site to the south). Point Creek leads into the Sprite River at a point 37 km (23 mi) downstream, which then drains into the Wilder River, 27 km (17 mi) further south. Both Point Creek and Boyle Creek are considered Class C waters, best suited for recreational fishing. Point Creek and its tributaries are shallow, rocky bottom streams. The major primary producers of these waters consist of several genera of diatoms, green and blue-green algae. The most common phytoplankton are Tubellaria, Fragillaria, Asterionella, and Cyclotella. The flow of these streams somewhat limits the abundance of macroflora. Forty seven fish species are known to occur within the county in the Wilder River watershed.

Most of these species are expected in Point and Boyle Creeks. Point and Boyle Creeks are also stocked with rainbow trout, and tiger muskellunge.

1.1.8 Land Use

The site, which is forested, is located in a rural land area. The general region in which the site is located is comprised mostly of forested land and active or inactive farmland. There are no farm dwellings or other residences located onsite. The site is not suited for any unique uses, but the soils are considered to be suitable for farming. There is no significant mineral resource development within 10 km (6 mi) of the facility. County plans for the site, which is not in a visually sensitive area, and surrounding land (2 to 7 km) include reforestation and compatible uses.

There are no known mineral resources of economical consequences within the vicinity of the site. Recovery operations in the area are limited to a small bedrock quarry located one mile to the north, and a sand and gravel quarry, located one mile to the east. No oil and gas reserves of economically recoverable quantities are known to exist in the area.

1.1.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 136. The average cation exchange capacity of the subsurface media is about 12 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 50 years. The horizontal saturated zone travel times from the edge (of the vertical projection into the saturated zone) of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 150 years (30 meters); to the closest drinking water well 2,450 years (500 meters); and to the nearest surface water discharge location, 4,950 years (1,000 meters).

1.2 Southeastern Site

The southeastern site is assumed to be located within the Liptone Upland segment of the Atlantic Coastal Plain physiographic province. For the purposes of this appendix, the southeastern site description is assumed to be consistent with the reference facility described in Appendix E.

1.3 Midwestern Site

Falling within the Central physiographic province, the midwestern site rests at an average elevation of about 247 m (810 ft) above mean sea level. The general topography of the site, which is shown in Figure J.4, is that of a well dissected plain which is virtually encircled by various branches of the West Fork of Finley Creek. The regional topographic surface undergoes only small changes in relief.

1.3.1 Geology

A considerable thickness (approximately 35 m or 115 ft) of unconsolidated deposits underlies the site. Most of this is composed of a rather impermeable glacial till consisting predominantly of pebbly and sandy clay and silt, and gumbotil. Gumbotil is a clay-rich till produced as a result of thorough chemical decomposition. Portions of the glacial drift may contain sand and gravel pockets of limited areal extent.

Southeast of the site is an area underlain by buried channel deposits reflective of an ancient stream channel. This channel consists of stream alluvium that filled the valley prior to or between glacial periods. The buried channel in the site area represents the upper reaches of a tributary to what is presently called the Washoe Channel. Evidence of this system is the increased depth to bedrock by about 23 m (75 ft).

The bedrock consists of approximately 30.5 m (100 ft) of Mississippian age rocks belonging to the Dette and Adams Series. The uppermost formation of the Dette series, the Pile shale, which generally acts as an aquiclude to the underlying Karesh and Becker formations, is absent from the site area. The Karesh limestone is thin and discontinuous over the Becker. Both formations are chiefly dense, crystalline, lithographic or tightly cemented fragmental limestones and dolomites with very low porosities. The basal 3 m (10 ft) of the Becker consists of cherty sandstone.

Underlying the Dette series are the dense, cherty dolomites and limestones of the Adams series. These rocks are exposed at the buried channel/bedrock contact point. These two series make up what is known as the Mississippian Aquifer. They are underlain by approximately 400 feet of siltstones and shales of Devonian age that serve as a good aquiclude to the underlying Devonian Aquifer. Stratigraphic sequences and the location of the ground-water table are illustrated in the geologic profile on Figure J-5.

The midwestern site is located within the tectonically stable interior of the North American continent. The closest area of major seismic risk covers the

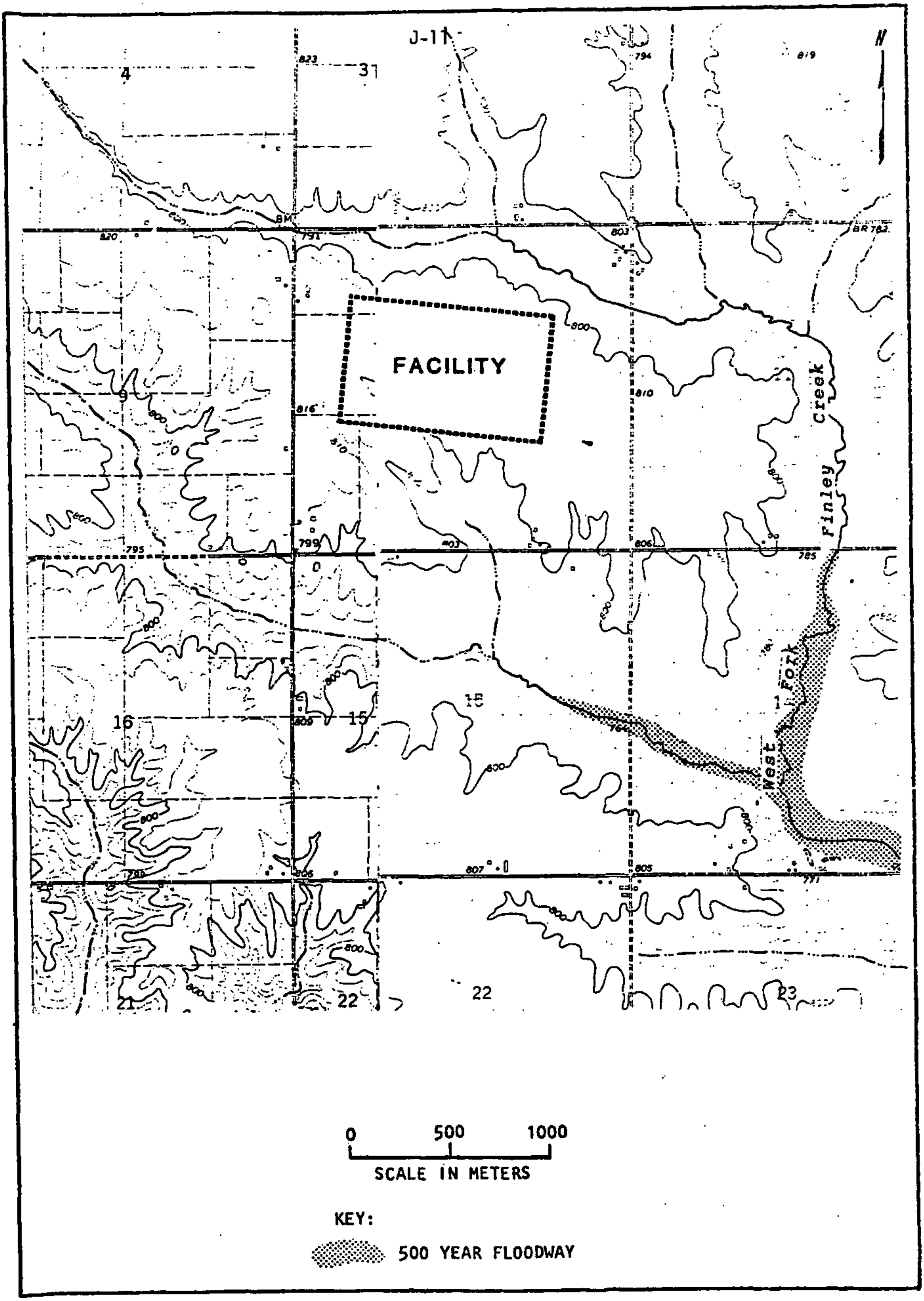


Figure J.4 Midwest Site

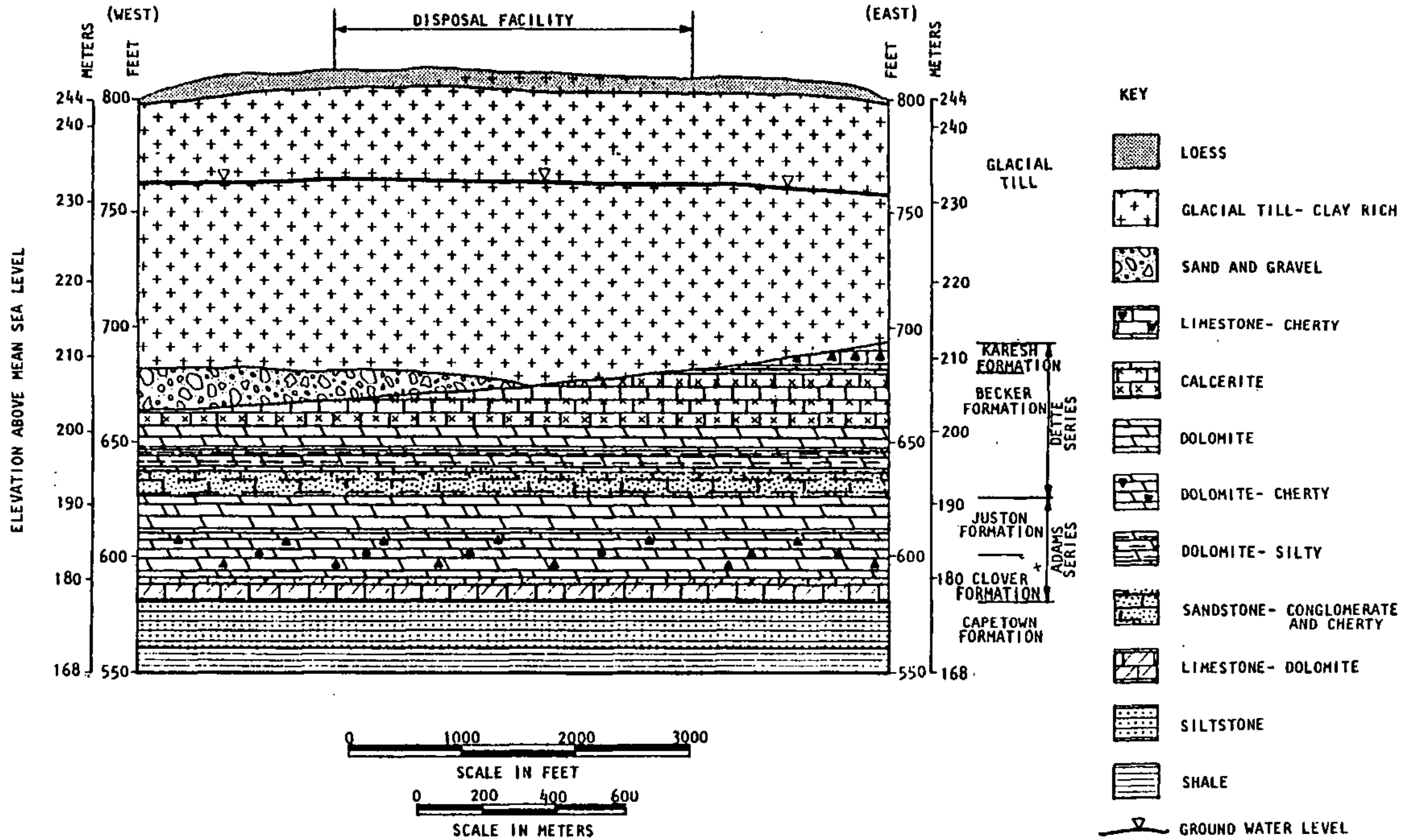


Figure J.5 Geologic Profile of the Midwest Site eastern section of the adjoining state to the north. The site area has a probable peak horizontal ground acceleration of less than 0.04 g, with a recurrence interval of more than 500 years. Within historical record, no evidence was found to indicate the occurrence of a capable fault within the site area.

1.3.2 Soils

The entire area in which the site is located is covered by about 3 to 3.7 m (10 to 12 ft) of Wisconsin loess, which is the parent material of the site soils. The predominant soil types are silty clay loams belonging to the Wancho, Houlik and Lyle series.

These soils are generally moderately-slow to moderately-well drained and have permeabilities ranging between 5 and 50 m/hr (0.2 to 2.0 in/hr). The soil is generally highly acidic in the topsoil layer and slightly acidic to neutral in the substratum. Organic matter content is consistently high throughout the series. Available nitrogen and phosphorus are low to medium, and the soil content of potassium and calcium is very low.

1.3.3 Ground Water

Ground water of appreciable amounts occur chiefly in the sand and gravel deposits associated with the glacial drift and buried channel systems. These "drift aquifers" are notably limited in areal extent, although they sometimes serve as sources for farmsteads and livestock drinking water. Water quality from the drift aquifers is generally good, being low in dissolved solids and mineral constituents; however, nitrates in excessive amounts are common, especially in those deposits close to heavily fertilized ground surfaces.

Thicknesses of about 15 m (50 ft) or more of sand and gravel have been associated with some of the larger buried valley systems. As the channel in the site proximity is more representative of the upper limits of a tributary to such a valley, it is likely to have lesser quantities of permeable sediments. Water from these deposits is more highly mineralized than in the drift aquifers. Permeabilities on the order of 0.048 to 0.48 cm/sec (1,000 to 10,000 gpd/ft^2) can be expected depending upon how well sorted the sand and gravel deposits are within these aquifers.

Water in these Mississippian rocks is generally confined to secondary openings, and movement is considered to be very slow. Specific capacities are estimated to be less than 1.0 gallon per minute per foot of drawdown. Based upon the dense, impervious nature of the rock, a permeability of 2.4×10^{-5} cm/sec (0.5 gal/day/ft^2) can be assumed. With little exception, water from the Mississippian aquifer in the site area offers good to fair quality water.

The depth to the seasonally high ground-water table under the site is expected to be about 12 m (38 ft) from the ground surface. Local ground-water movement in the drift aquifer will be governed by the topography, draining toward and being discharged into the various branches of the West Fork of Finley Creek. Ground water from the surficial aquifer, and also from the shallow bedrock aquifer, can be expected to discharge to the buried alluvial deposits. The regional ground-water flow in the Mississippian aquifer is to the south-southeast as controlled by the nearest major stream, the Deer River.

Ground water usage in the area is limited to consumption as needed by local homes and farmsteads for domestic, irrigation and livestock supplies. It is estimated that the majority of wells tap Mississipian aquifers and to a lesser degree, the drift aquifers. Yields of less than 76 lpm (20 gpm) are the rule for this area. The only municipal supply in proximity to the site belongs to the town of Mica, located about 5.6 km (3.5 mi) to the southeast. Four of the nine municipal wells tap the Lower Mississippian Aquifer. The remaining wells utilize the Lower Ordovician Aquifer.

1.3.4 Surface Water

The site is located on a section of the Great Plains that is undergoing dissection as a result of recent climatic change. Approximately 90% of the streams in the drainage area are intermittent, flowing only 6 to 8 months of the year. The drainage density of the basin is 0.64, indicating a coarse drainage texture which is typical of this region. Flow rates from the site average between 0.74 to 0.99 m^3/s (26 and 35 cfs) for the year.

Since the site is of limited areal extent, the correlation between precipitation and stream discharge is very close. Peak discharge rates are related to precipitation events of high intensity. Between 60 and 80 percent of the precipitation in the drainage basin is discharged as surface runoff. Unit hydrograph analysis of the site area indicates that peak flow usually develops between 6 and 7 hours after precipitation begins. Base flow and return flow play important roles in the basin drainage; the extent is determined by the intensity and duration of the precipitation event.

As expected, the highest stream discharge rates are associated with rain storms of limited duration but with high intensity (ranging between 102 and 152 mm/hr). The 500-year flow floodway is delineated in Figure J.4.

During the development of the site the discharge rate is expected to increase as the area is cleared of vegetation and impervious material is placed over the disposal cells. While the site development will decrease the time to peak discharge and increase the peak flood stage, there will be no significant risk of flooding at the site due to the elevation differences between the area and the site outflow. While overland flow of considerable velocity may be expected during site development, prudent drainage engineering will be able to divert flow, reduce velocities and limit erosion of the site.

1.3.5 Meteorology

The area has a humid continental climate, with a total annual local precipitation of 777 mm (30.5 in). Approximately two-thirds of the annual precipitation occurs during the months of April through September. The source of this precipitation is the warm moist southerly air from the Gulf of Mexico. The normal mean snowfall for the site area is approximately 686 mm (27 in).

The average annual temperature in the site vicinity is approximately 11°C (51.0°F). July is the hottest month, having an average daily maximum of 31°C (87°F) and an average daily minimum of 18°C (64°F). During January, the coldest month, the daily temperature range is approximately -0.6°C (31°F) to -11°C (12°F).

The prevailing wind direction at the site is southerly at an average speed of 17 km/hr (9.0 knots). During the months November through March, a northwesterly wind component develops in response to the Canadian cold air outbreaks. Wind speeds during these months average 22 km/hr (12.1 knots).

Severe weather events such as thunderstorms and tornadoes occur during midspring to late summer. Statewide occurrences of tornadoes average about 10 for any given 8 year period. From the period 1920 to 1960, there have been approximately 75 occurrences within 2° latitude/longitude square inclusive of the site.

Since the site has a pronounced continental type of climate, it has inversion frequencies closely related to the diurnal cycle. In general, inversions occur 20 to 30% of the time during spring and summer, while during the fall and winter months, inversions may be expected about 30 to 45% of the time. The higher frequency during the fall and winter is probably a reflection of the relatively low number of storms in the fall and maximum length of stable nocturnal period in winter. The opposite is true for the summer months. As a result, seasonal annual morning and afternoon mixing heights vary by small amounts.

1.3.6 Terrestrial Ecology

The natural vegetation within the vicinity of the site is a mixture of oak-hickory forest and bluestem prairie. The forest community occurs primarily along valley slopes and upland ridges. Big bluestem is the dominant grassland plant where the prairie remains. However, most of this area is cropland. Two terrestrially environmentally sensitive areas, Deer River Access and Chatham Timbers, are located 18 km (11 mi) to the southwest and 38 km (24 mi) to the south, respectively. Green Lake, which is a prime recreational fishing area, is located 21 km (13 mi) southeast.

The two major land uses of the county in which the site is located are pastureland (24 percent) and row crops (65 percent), with corn and soybeans representing the dominant crops. Approximately 35 and 12 percent of the county, respectively, are planted in these crops. Most of the naturally occurring prairie has been lost in the county. Existing grasslands, dominated by introduced species, are interspersed in 60 to 80 ha (150 to 200 acre) blocks throughout the county.

Almost 60 percent of the land area adjacent to the site is planted in corn. Four small woodlots, about 4 ha (10 a) total, are found in the near vicinity of the site--either adjacent to residences or farm buildings, or along creek boundaries. White oak, red oak, and shagbark hickory dominate these woodlands. Small blocks of grassy areas occur along stream banks, roadsides and other areas. Common introduced grasses include bluegrass and smooth brome. Similar ground cover types are found within an 8 km radius of the site, with slightly more oak-hickory forests occurring along the tributaries of Deer River.

No federally declared endangered or threatened species have been observed on or near the site. The most common mammals found onsite and within a five mile radius are those for which corn is a predominant food source, and can live in proximity to man. The most abundant species include the racoon, striped skunk, eastern cotton-tail, opossum and fox squirrel. Several burrowing mammals are also found in the area, primarily in fields not actively cultivated; these include the badger, plains pocket gopher and thirteen-lined ground squirrel. The badger and pocket gopher dig tunnels in search of food that can be 1.2 to 1.5 m (4 to 5 ft) in depth and up to one hundred meters long.

Most of the mammals that utilize the site have small home ranges, e.g.: thirteen-lined ground squirrel - 0.8 to 1.21 ha (2 to 3 acres); eastern cotton-tail - 3 to 8 ha (7 to 20 acres); and opossum - 6 to 16 ha (15 to 40 acres). The raccoon, with a maximum range of 3.2 km (2 mi), and an average of 1.6 km (1 mi), has the largest home range of those species expected in this area.

Corn very often is a major winter food source for many upland game birds, including birds found in the area. The ring-necked pheasant, and bobwhite quail are the species most commonly hunted. Black ducks, mallards and pintails are also numerous in the area, and feed heavily on corn.

Numerous resident bird species are also found onsite and in the surrounding cornfields. The most common species found, and which feed extensively on corn, include the redwing, cardinal, meadowlark, purple grackle, and common crow. Resident birds of prey include the red-tailed hawk and great-horned owl. Transient species include the coopers hawk, broad-winged hawk, and red-shouldered hawk. As a result of ongoing agricultural activities, the reptile and amphibian population of the area is limited. An occasional eastern plains garter snake, bullsnake, or black rat snake may be found.

1.3.7 Aquatic Ecology

With the exception of the northwestern border, the site is surrounded on all sides by the West Fork of Finley Creek, and other unnamed intermittent tributaries. Finley Creek feeds into the Deer River approximately 51 km (32 mi) downstream. There are no federally declared wild or scenic rivers within five miles of the site.

The west fork of Finley Creek and its tributaries are Class B warm waters. Primary uses of the creek are for wildlife, fish, aquatic and semiaquatic life, and secondary contact water uses. Although the soils along the stream banks are moderately to highly erodable, the vegetated banks limit the amount of sediments that enter the streams. No federally declared endangered or threatened fish or snails are expected in these streams.

1.3.8 Land Use

The site is located on agricultural land used extensively (85%) for cultivation of crops, mostly corn. Five houses are located within 5 km of the site. The site vicinity contains 4 towns--Mica, Grendle, Reed and Lyme--but most of the land is not developed intensively. Hayer Park (10 acres) is located 4.8 km from the site. There are no other community facilities, historic places, or other visually sensitive land uses within a 8 km radius. Two state-owned lands, Lake Darling and Deer River Access, are located within 24 km of the site.

The chief source of economically important resources in the state lies in the substantial coal resources associated with Pennsylvanian age rocks. No such deposits occur under the site as the initial bedrock encountered is of Mississipian age. There is a potential for some natural gas deposits. However, the Ordivician source rocks are thin, making recovery unconsequential and uneconomical.

1.3.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is 93. The average cation exchange capacity of the subsurface media is about 12 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 85 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 30 years. The horizontal saturated zone travel times from the edge (of the vertical projection onto the saturated zone) of the disposal cell closest to the discharge locations to the restricted area fence, 90 years (30 meters); to the closest drinking water well, 2,070 years (1,250 meters); and to the nearest surface water discharge location, 3,770 years (2,500 meters).

1.4 Southwestern Site

The southwestern site is assumed to be located within the Northern High Plains subdivision of the Great Plains physiographic province. The regional topography shows sharply contrasting flat plains and rolling to rugged erosional breaks (see Figure J.6). The plains are about 17,872 km^2 (6,900 mi^2) in areal extent and show a gradual eastward slope on the order of 0.2%. The site has an estimated average elevation of 1,219 m (4,000 ft) above mean sea level. As is characteristic of the area, the site is flat. Drainage is to the southeast and southwest to various intermittent branches of Hotsprings Creek.

1.4.1 Geology

Below the surface cover of loam and clay-loam soil are Pliocene age deposits of the Bixler formation. These sediments were eroded from the ancient Rocky Mountains and transported by streams to this area. Because of their origin of deposition, their character varies both vertically and horizontally. As a general rule, however, the sand and gravels are in the basal portion of the formation.

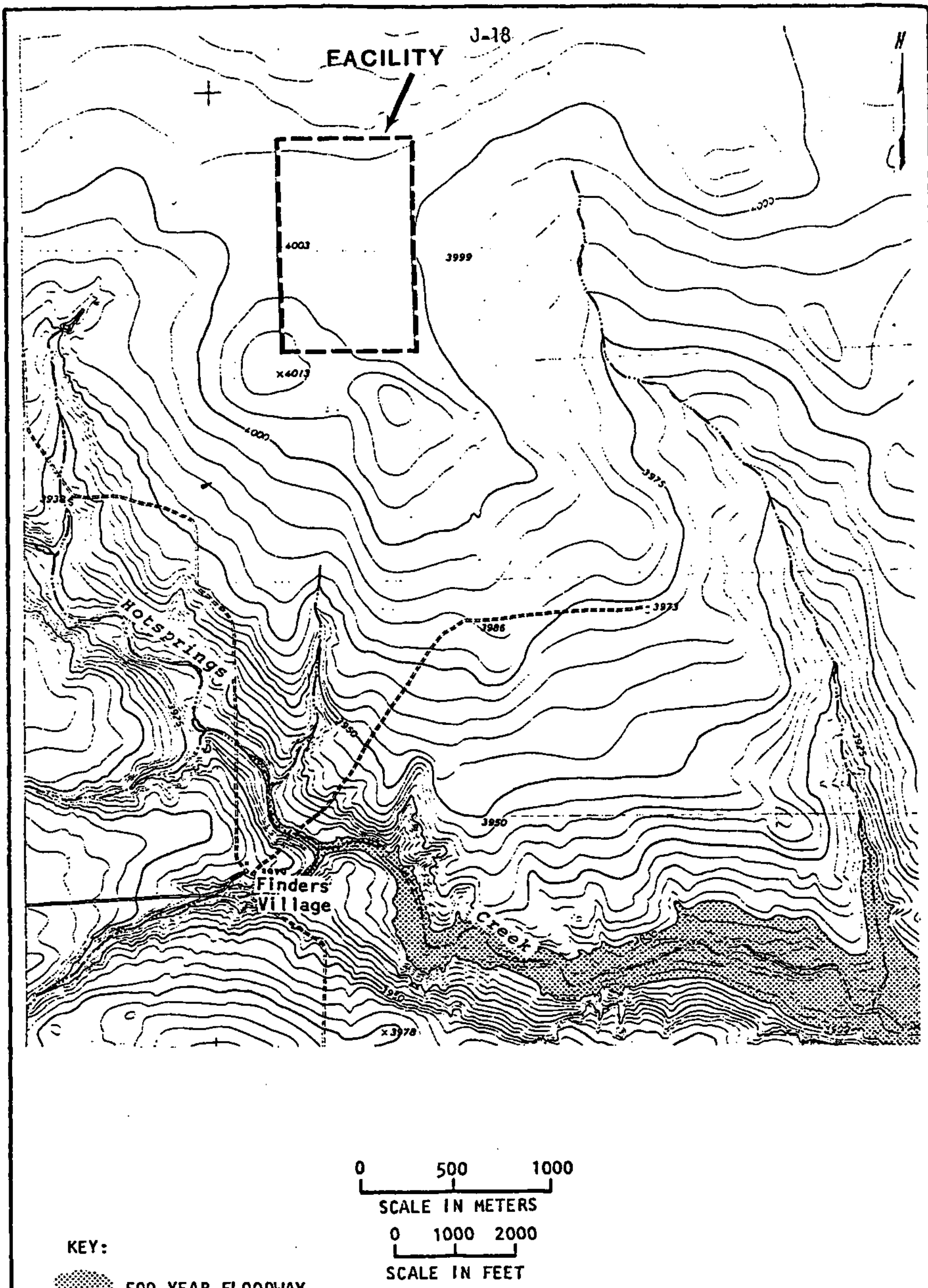


Figure J.6 Southwest Site

The Bixler Formation is about 91 m (300 ft) thick in the site area. The upper 12 to 15 m (40 to 50 ft) is composed of caliche, a calciumrich, carbonate-impermeable sandy clay which acts in a similar manner as a hardpan. Effects of the semiarid climate have cracked the upper 0.9 to 1.5 m (3 to 5 ft) of the caliche. Underlying the caliche is approximately 15 m (50 ft) of dense, brown clay. Thin, discontinuous streaks of sand are also associated with the clays. The balance of the Bixler is principally composed of sand and gravel, extending down to the eroded surface of the Triassic rocks.

The Triassic shales and sandstone belonging to the Maxwell group are estimated to be about 152 m (500 ft) thick in the site area. The first material encountered under the permeable Bixler strata is a red clay, indicative of the weathered shale surface. A schematic representation of the site geology is shown in the geologic profile in Figure J.7.

The site falls within an area designated as having a peak horizontal ground acceleration of less than 0.04 g with a recurrence interval of more than 500 years. No evidence was found to indicate the occurrence of capable faults under or near the site.

1.4.2 Soils

The predominant soil types underlying the site are loams and clay loams belonging to the Starble, Nester, Wixman and Jeeper series. They were formed from moderately fine-textured, calcareous, windblown sediments derived mostly from alluvial outwash from the Rocky Mountains.

Because rainfall is low, and there are long, dry periods, soil development has been slow. The soils are seldom wet below the root zone, and, as a result, many of the soils have a horizon of powdery lime accumulation. Leaching has not yet removed free lime from the upper layers of the calcareous Starble and Wixman soils. Soils belonging to the Nester and Jeeper series tend to be more neutral.

Calcium contents are high in all the soils. Generally, the prairie type of vegetation contributes large amounts of organic matter to the soil. The soils are rather deep (up to 2.5 m) and well-drained, having nearly level to gentle slopes. Runoff is generally slow and permeability values range between less than 1.5 to 50 mm/hr (0.06 to 2.0 in/hr).

1.4.3 Ground Water

The Bixler formation is an unconfined aquifer with very limited consumptive use. The water occurs under water table conditions, and the differences in the thickness of the water saturated material are closely related to the thickness of the Bixler formation. The saturated thickness under the site is only abut 7.6 m (25 ft) as the water table lies some 84 m (275 ft) below ground surface. Available data indicates that the Bixler is the local source for recharge to the Triassic rocks where they are in contact.

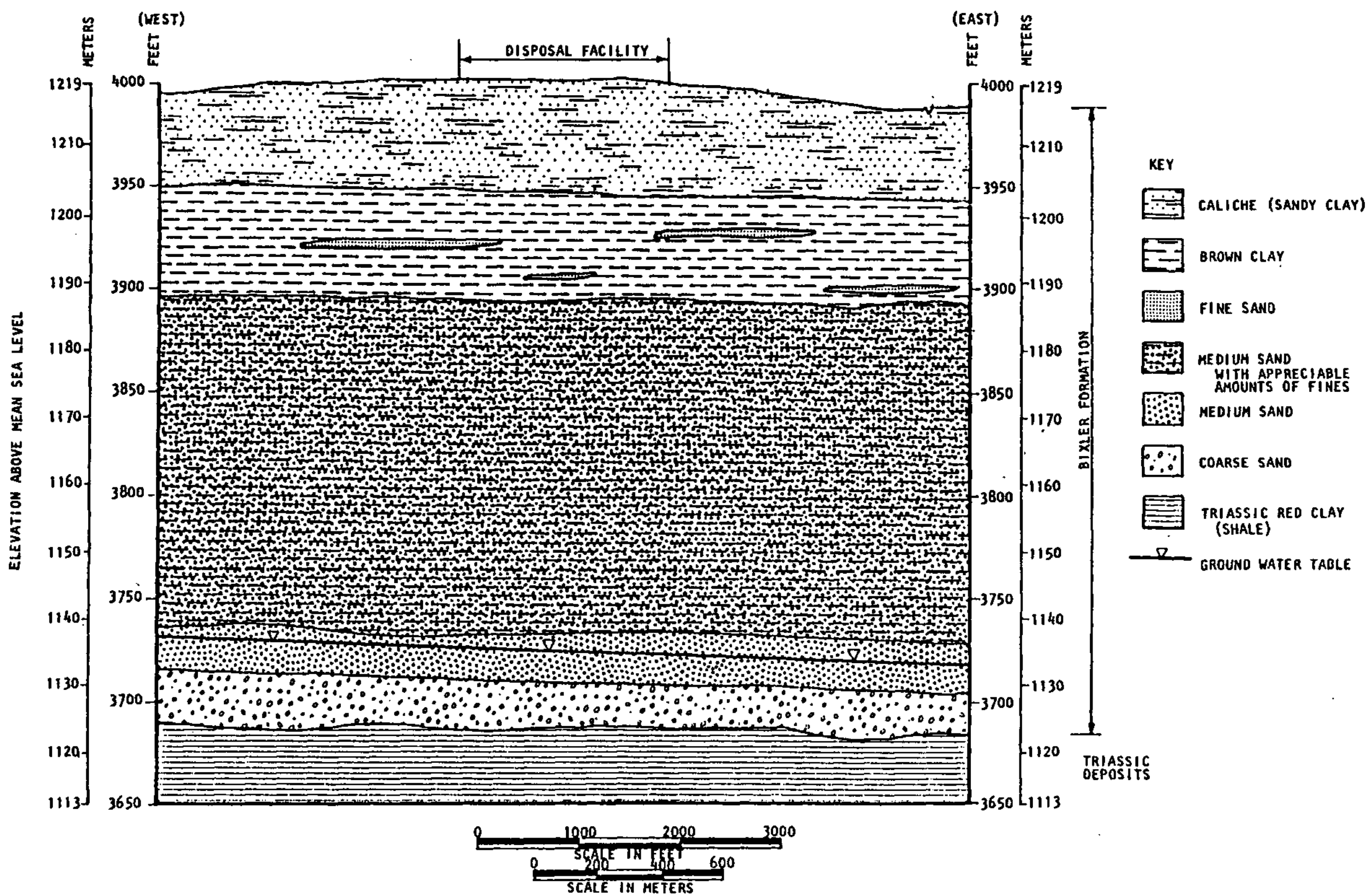


Figure J.7 Geologic Profile of the Southwest Site

The source of water (recharge) to the Bixler, and thence to the Triassic rocks, is precipitation on its more permeable surfaces. The amount of precipitation that enters the ground water is a very small percentage of the total precipitation falling at the surface. It has been estimated that the quantity of precipitation annually reaching the ground water is negligible. For the purposes of this environmental impact statement, however, it is assumed that the annual percolation is 1 mm. Due to the rather impervious nature of the onsite surficial materials, most of the precipitation will be lost by evaporation or drain to Hotsprings Creek as runoff. Part of this runoff will percolate downward through the coarser stream deposits and enter the ground water regime. This probably constitutes the major source of recharge within the area of the site. Some infiltration may work its way through the fractured portions of the caliche and slowly downward to the water table, but this is of limited quantity.

Under natural hydraulic gradient conditions, the water table slopes to the east, generally parallel to the surface slope which is about 0.2%. The average permeability of the Bixler-Triassic aquifer in this area is estimated to be 4.7×10^{-3} to 9.4×10^{-3} cm/sec (100 to 200 gal/day/ft^2).

Ground water within the site vicinity is used almost exclusively as a supply for livestock with a few domestic wells serving ranches. The wells are generally powered by windmills and generate yields not likely to be greater than 7.6 to 11.4 liters/min (2-3 gpm). The nearest irrigation well is located about 13 km (8 mi) from the site.

1.4.4 Surface Water

Elevations on the site range between 1,169 and 1,223 m (3,835 and 4,013 ft) above mean sea level. Total stream length above the site is over 90 km (295,680 ft). With the limited precipitation in the region, streams flow intermittently throughout the year. A wide variation in discharge occurs at the site. Since no base flow is known to occur in the area, precipitation accounts for all of the stream discharge. Short duration, high intensity thunderstorms account for the peak discharges from the site.

While the area of the basin receives considerable intense rain (greater than 50 m/hr), most peak flow is dissipated before discharge at the outlet. Peak discharge occurs when the rain event is within 32 km (20 mi) of the outlet. Analysis of unit hydrograph of the site area and flow data indicate that high discharge rates of up to 28.2 m^3/sec (1,100 cfs) may be expected to occur at least once a year. The 500 year flood has been determined to be about 736 m^3/sec (26,000 cfs) and the floodway is delineated on Figure J-6. As shown, the site is well above the floodway.

1.4.5 Meteorology

The climate of this site is considered semiarid, which is characterized by low humidity, wide temperature and precipitation variations, and frequent windstorms. The average annual precipitation for the site area is approximately

485 mm (19 inches). Departures from the norm can be great with extreme yearly totals ranging from 243 to 1,010 mm (9.56 to 39.75 in). Nearly three-quarters of the total annual precipitation occurs during the growing season from April through September, primarily in the form of thundershowers.

The average annual temperature for the area is about 14°C (57°F). Maximum temperatures occur in the mid-summer months of June, July, and August. Rapid and wide variations are common, especially during the winter months when cold fronts from the Rocky Mountains and Plains States sweep across the plains. Temperature drops up to 16°C (60°F) occurring within a 12-hour period may be associated with these fronts. The highest recorded temperature in the region was 42°C (108°F) and the lowest was -27°C (-16°F).

The prevailing winds from March through October are southerly at 25 km/hr (13.6 knots), and southwesterly at 21 km (11.4 knots) during the winter months. The annual mean speed for all directional components is 24 km (13 knots) and southerly. These winds contribute to the evaporation rate associated with the region. The strongest winds generally occur in March and April and are associated with thunderstorm activity. The strongest winds recorded (134 km/hr in 1949) were associated with a tornado; however these climatic events are rare.

1.4.6 Terrestrial Ecology

The site is located in the High Plains area, also known as the Tinson Province. This area is a relatively level high plateau, and is better drained than most other regions in the state. The shorter growing season (179-225 days) and lower annual average temperature (12° to 13°C) found in this region, compared to other parts of the state, play an important role in the types of plants and animals found here.

The area has been characterized (within a 40 km radius of the site) as Grama Buffalo Grasslands. The most abundant native plant species in this short grass/mixed grass prairie are buffalo grass, and blue grama. Total ground cover is relatively dense, and tends to increase under grazing. The preponderance of grass species results in large quantities of organic materials in the form of living and dead grass roots within the first ten to twelve centimeters of soil (some roots of blue grama and buffalo grass extend to 0.9 m however). The vegetative cover of the site is typical of the region. Although various species of trees, including oaks, elms and hackberries are often found along stream floodplains and steep-walled canyons, these are not found along Hotsprings Creek, an intermittent stream, or its feeder streams, which surround the western, eastern, and southern portions of the site. Federally declared endangered species have not been observed within the site.

The mammalian fauna of this general area includes at least 50 to 60 species, two of which are restricted to this area of the state: the swift fox and plains pocket mouse. During the hot daylight hours, a large number of mammals of this semiarid region live in burrows which they either dig themselves, or which they share or overtake from other species. The larger species which create their own underground burrows include the badger, plains pocket gopher, and swift fox. Only the former two species were observed within 1 km of the site. The fox uses its burrow, which averages 3.7 m (12 ft) in length and 81 cm (32 inches) in depth, as a den. Many other species also dig their own burrows, or use those of others, to escape the heat and predators, to search for food (insects, seeds or other burrowing mammals) or to use as dens. However, these burrows are shallow.

Other nonburrowing mammals characteristic of this area and which have been observed onsite include the coyote, pronghorn antelope, bobcat, jack rabbit, and eastern cottontail. While six species of bats are known to inhabit the county, none were observed to nest at the site. The most common game species found on the site are rabbit, quail, dove and pheasant.

The mixed grass prairie found onsite and in the general area does afford suitable habitat to numerous resident bird species. The most common small birds include the Western meadowlark, dickcissel, bobolink, savanna sparrow, and prairie chicken. The most numerous resident birds of prey include the golden eagle, horned owl and burrowing owl.

Several species of lizards and snakes also inhabit the site. The more common ones include the northern earless lizard, prairie lizard, great plains skunk, prairie rattlesnake, western diamondback rattlesnake, and bullsnake. Only the last two species have been observed within the site boundaries. As with many mammals of this region, these reptiles extensively utilize underground burrows. Most of the snakes use rodent burrows both for cover and in search of food. The great plains toad and plains and western spadefoot toads dig their own underground tunnels, which can range from several centimeters to a meter in depth.

1.4.7 Aquatic Ecology

The aquatic environment of the site is limited to Hotsprings Creek and its two feeder streams, all intermittent, which surround the site to the east, west, and south. This creek remains intermittent until approximately nine miles prior to its confluence with the Montreel River approximately 136 km (85 mi) downstream. The only other tributaries to Hotsprings Creek occur within an 8 km (5 mi) radius of the site. After rainstorms when water does flow in this stream, aquatic biota is limited to algae, insects (which use the water to breed), and potential fish species such as minnows and sunfish. These fish survive the dry seasons by gathering in small pools of water that may remain throughout the year, and are then dispersed throughout the stream with the flowing waters.

1.4.8 Land Use

The site is located near the administrative borders of a national grassland administered by the USDA, on open grassland. The site itself was privately owned before purchase by the state. There are no residences onsite or within the close vicinity (1 mi) of the site.

The site region is a plain containing numerous parcels of federal grassland, distributed throughout this portion of the state and into neighboring states.

Portions of the site are used at times for grazing cattle. The national grassland is the overriding factor influencing land use in the area, and this is not expected to change significantly in the foreseeable future.

The only known mineral resource occurring in the site area is caliche. This calcium carbonate cement is associated with sand and gravel deposits of the Bixler formation, and may be suitable for use as aggregate. However, these deposits are widespread throughout the entire region and do not represent unique resources.

Whereas numerous producing oil and gas wells have been drilled in the adjoining county to the east of the site, no historical production has occurred within the county. Prospect wells drilled within proximity to the site have not indicated the presence of oil or gas reserves of recoverable quantity.

1.4.9 Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following: The precipitation-evaporation (PE) index of the vicinity is 21. The average cation exchange capacity of the subsurface media is about 5 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical travel time (and distance) from the bottom of the trenches to the saturated zone is 275 years. The horizontal saturated zone travel times (and distances) from the edge (of the vertical projection onto the saturated zone) of the disposal cell closest to the discharge locations are the following: to the restricted area fence, 5 years (30 meters); to the closest drinking water well, 300 years (3,000 meters); and to the nearest surface water discharge location, 600 years (6,000 meters).

2. SUMMARY OF REGIONAL ENVIRONMENTAL PARAMETERS

This section presents a summary of the regional environmental parameters and characteristics presented in this appendix and used in this EIS to calculate radiological and economic impacts from LLW management and disposal.

The assumed population distribution in the vicinity of each of the four regional sites at the year 2000 (postulated year of end of facility operations) is presented in Table J.1.

Water balance calculations for determining the amount of precipitation reaching the saturated zones of the regional sites (i.e., the amount of percolation) are presented in Tables J.2 and J.3. As shown in Table J.3, the water balance calculations for the southwestern regional site indicate that there is no calculable percolation reaching the saturated zone. However, for purposes of determining bounding impacts from waste disposed at this site, it is assumed that the percolation coefficient equals 1 mm at the southwestern site.

Based upon this information, information presented in this appendix, Sections 1.1 through 1.4, and information presented in Appendix E, environmental parameters specific to the four regional disposal sites may be calculated. A list of the region-dependent parameters is included in Table J.4, together with the parameters

Table J.1 Population Distributions for Regional Case Studies

Distance From Facility	Northeast	Southeast	Midwest	Southwest
0-5 miles	3,440	2,024	3,070	59
5-10 miles	20,513	8,115	4,998	180
10-20 miles	73,636	36,000	27,890	3,529
20-30 miles	121,559	124,995	104,181	9,062
30-40 miles	556,639	203,435	121,893	4,888
40-50 miles	1,012,788	104,933	359,146	27,158

Table J.2 Water Balance Analysis Data and Assumptions

Legend: All units in (mm of water) except for C which is dimensionless.

S_M = Maximum Soil Moisture Storage
P = Precipitation
C = Surface Runoff Coefficient
R = Surface Runoff
I = Infiltration
PET = Potential Evapotranspiration
I-PET = Difference Between (I) and (PET)
CNS = Cumulative Sum of Negative (I-PET)
S = Soil Moisture Storage
dS = Change in Soil Moisture Storage
AET = Actual Evapotranspiration
PERC = Percolation into Ground Water System

Assumptions:

P = Data from Representative Location (Ref. 24)
PET = Data from Representative Location (Ref. 24)
C = Estimated for Each Region Based on Typical Soil Descriptions of Region.
S_M = For Humid Sites Assumed 100 mm and for Arid Site Assumed 50 mm.

Calculations: Follow in Table J-3.

Table J.3 Detailed Water Balance Calculations

	J	F	M	A	M	J	J	A	S	O	N	D
NORTHEAST REGION: S_M: 100 mm												
P	71	65	73	72	92	110	114	110	92	86	78	71
C	.20	.20	.20	.20	.15	.15	.15	.15	.15	.18	.20	.20
R	14	13	15	14	14	16	17	16	14	15	16	14
I	57	52	58	58	78	94	97	94	78	71	62	57
PET	0	0	0	28	77	111	129	110	75	38	6	0
I-PET	57	52	58	30	1	-17	-32	-16	3	33	56	57
CNS						-17	-49	-65				
S	214	266	324	100	100	84	60	51	54	87	100	157
dS	57	52	58	0	0	-14	-24	-9	3	33	13	57
AET	0	0	0	28	78	108	121	103	75	38	6	0
PERC	0	0	0	30	1	0	0	0	0	0	43	0
SOUTHEAST REGION: S_M: 100 mm												
P	80	100	96	84	82	102	149	147	103	64	77	81
C	.14	.14	.14	.14	.14	.12	.12	.12	.12	.12	.14	.14
R	11	14	13	12	11	12	18	18	12	8	11	11
I	69	86	83	72	71	90	131	129	91	56	66	70
PET	13	15	37	65	115	158	172	157	114	64	29	13
I-PET	56	71	46	7	-44	-68	-41	-28	-23	-8	37	57
CNS					-44	-112	-153	-181	-204	-212		
S	100	100	100	100	64	32	21	16	12	11	48	100
dS	0	0	0	0	-36	-32	-11	-5	-4	-1	37	52
AET	13	15	37	65	113	147	162	151	10	63	29	13
PERC	56	71	46	7	0	0	0	0	0	0	0	0
MIDWEST REGION: S_M: 100 mm												
P	21	23	36	73	108	108	94	91	101	64	33	25
C	.15	.15	.15	.15	.13	.10	.10	.10	.10	.13	.15	.15
R	3	3	5	11	14	11	9	9	10	8	5	4
I	18	20	31	62	94	97	85	82	91	56	28	21
PET	0	0	6	43	88	127	147	131	86	44	7	0
I-PET	18	20	25	19	6	-30	-62	-49	5	12	21	21
CNS						-30	-92	-141				
S	101	121	10	100	100	74	39	24	29	41	62	83
dS	18	20	0	0	0	-26	-35	-15	5	12	21	21
AET	0	0	6	43	88	123	120	97	86	44	7	0
PERC	0	0	25	19	6	0	0	0	0	0	0	0

Table J.3 (continued)

	J	F	M	A	M	J	J	A	S	O	N	D
SOUTHWEST REGION: S_M: 50 mm												
P	6	10	20	48	71	79	64	72	37	45	19	14
C	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
R	1	1	2	5	7	8	6	7	4	4	2	1
I	5	9	18	43	64	71	59	65	33	41	17	13
PET	1	4	21	47	86	129	154	136	95	49	15	0
I-PET	4	5	-3	-4	-4	-58	-95	-71	-62	-8	2	13
CNS			-3	-7	-29	29	-182	-253	-315	-323		
S	20	25	23	20	14	8	3	1	1	1	3	16
dS	23	9	-2	-3	-6	-6	-5	-2	0	0	1	18
AET	1	4	20	46	70	76	67	67	95	41	15	13
PERC	0	0	0	0	0	0	0	0	0	0	0	0

Table J.4 Region Index Dependent Parameters

Symbol	Scenario	Environmental Property
TPO	Accident	Air-to-air transfer factor FSC
	Construction	Soil-to-air transfer factor FSA
	Agriculture	Soil-to-air transfer factor
QFC	Groundwater	Dilution factor TTM
	Groundwater	Water travel time TPC
	Groundwater	Peclet number
RGF	Groundwater	Factor rg
RET	Groundwater	Retardation coefficients
PRC	Groundwater	Infiltrating percolation
POP	Exposed Waste	Air-to-air and surface water transfer factors.
DIST	Transportation	One-way travel distance
STPS	Transportation	Number of stops per trip
CASK	Transportation	Cask days per round-trip

symbols used in the computer codes developed by Dames & Moore of White Plains, NY for this EIS. Values determined for each of these parameters for each of the four regional sites are provided in Table J.5.

Use of a specific set of property values to calculate impacts is determined by the value of the regional index, IR (See Appendix G). The transfer factors are used to calculate the site selection factors (f_s) for the accident, intruder-construction, intruder-agriculture, and exposed waste scenarios are described in Sections 3.3, 3.6, and 3.7 of Appendix G. The parameters for the ground-water scenarios are used to calculate the waste form and package factors (f_w) and the site selection factors (f_s) for these scenarios as also described in Section 3.5 of Appendix G. The transportation parameters are used to calculate radiological and economic impacts of waste transport to the regional disposal sites as described in Section 4 of Appendix G. Additional information regarding the use of the parameters in the computer codes is provided in Appendix H.

Table J.5 Environmental Parameters for Regional Locations

Parameter	Symbol	Northeast	Southeast	Midwest	Southwest
Accident Scenario					
Fire	TPO(1)	1.83E-10	1.83E-10	1.83E-10	1.83E-10
Single-Container	TPO(2)	2.61E-12	3.32E-12	2.55E-12	1.79E-12
Intruder Scenarios					
Construction	FSC	9.18E-12	2.01E-11	2.51E-11	2.64E-10
Agriculture	FSA	2.96E-11	3.18E-11	3.28E-11	8.06E-11
Exposed Waste Scenario					
Intruder-Air	POP(1)	1.01E-09	3.50E-10	3.86E-10	2.66E-11
Erosion-Air	POP(2)	1.51E-09	5.25E-10	5.79E-10	3.99E-11
Surface Water	POP(3)	1.12E-07	1.12E-07	1.12E-07	1.12E-07
Groundwater Scenario					
Travel Times - years					
Between Sectors	DTTM	400	64	120	8
Individual Well*	TTM(1)	200, 350	42, 66	130, 175	283, 280
Population Well	TTM(2)	2500	400	2100	580
Population Surface	TTM(3)	5000	800	3800	880
Peclet Numbers					
Between Sectors	DTPC	800	1600	800	800
Individual Well*	TPC(1)	400, 700	1300, 1900	400, 700	1300, 1600
Population Well	TPC(2)	10000	10000	12500	30000
Population Surface	TPC(3)	20000	20000	25000	60000
Dilution Factors - m^3					
Individual Well	QFC(1)	7700	7700	7700	7700
Population Well	QFC(2)	2.0E+5	2.0E+5	2.0E+5	2.0E+5
Population Surface	QFC(3)	4.5E+6	4.5E+6	4.5E+6	4.5E+6
Goemetric Reduction					
Individual Well	RGF(1)	1	1	1	1
Population Well	RGF(2)	1	1	1	1
Population Surface	RGF(3)	1	1	1	1
Percolation - mm					
Regular Cover		74	180	50	1
Thick Cover		38	30	25	1
Retardation Coefficient Set Used	NRET	4	3	3	2
Transportation					
Oneway Distance (mi)	DIST	300	400	600	1000
Stops Along the Way	STPS	1	1	2	3
Cask Turnaround (days)	CASK	2	3	5	8

*The first values listed are for the intruder well, the second are for the boundary well.

Appendix K

FINANCIAL ASSURANCES FOR CLOSURE, POSTCLOSURE, AND ACTIVE INSTITUTIONAL CONTROL FOR AN LLW DISPOSAL FACILITY

1. OVERVIEW

The Commission staff has evaluated the need for financial requirements for a license applicant interested in siting and operating a low-level waste site. Based on their analysis, the staff has recommended that an applicant for a license meet certain financial standards so that financial responsibility for closure, postclosure, and active institutional control is provided by the applicant, and not by the taxpayers. The recommended financial requirements are in two parts: short-term financial assurances to cover the costs of closure and postclosure care, and long-term financial arrangements to cover the costs of active institutional control, or long-term care for a period not to exceed one hundred years. Since these are two separate concepts, the subjects of short-term and long-term financial requirements are dealt with separately in two sections of this appendix.

1.1 Need for Financial Protection Requirements

Financial assurance requirements for low-level waste disposal facilities are needed to help ensure the long-term protection of the public health and safety and the environment. A review by the staff of the operating experiences at both hazardous waste and LLW disposal sites reveals that sites of both types did not adequately plan for closure and long-term care activities. With respect to the LLW sites, however, state and federal governments recognized the need to care for the sites over the long term. The state and federal governments required the LLW sites to be located on federal or state government-owned land and funds were collected for long-term care activities. In most cases, however, the funds collected for long-term care activities (e.g., the Maxey Flats, Kentucky site) were not adequate and there was essentially no financial planning for contingencies that might occur, (e.g., the need to pump trenches and treat trench leachate). In addition, until recently little planning or financial assurance was provided for funding the final closure and stabilization of the existing sites. This has led to a situation where financial responsibility for the continued assurance of protection of the public health and safety at several of the existing closed sites already has or could become a responsibility of the state or federal government. Early proper financial planning to assure the availability of adequate financial resources for closure, contingencies, postclosure care, and institutional control could have prevented this from happening.

As discussed later in the review of the operating histories of low-level waste disposal sites, the necessary closure and long-term care activities have in some cases not been undertaken, or have had to be conducted by the state government, because of the lack of planning for and lack of financial assurances for such activities. The possibility that a licensee will be unable to assume financial responsibility for closure, postclosure, and long-term care activities at a site is increased as a result of the period when these activities begin, relative to when revenues are received. Closure, postclosure, and active institutional control costs are generally incurred after the site operator is no longer receiving revenues from waste generators. Thus, proper planning during the operating phase when revenues can be accrued is essential Based on these considerations, there is a strong need for regulatory requirements to ensure that: (1) the licensee has sufficient financial resources to provide for final closure and postclosure care of the site, and (2) the licensee provides financial assurance for the active institutional control period after the site is closed and stabilized. The staff believes that these closure and active institutional control costs should be identified early and should be provided for as part of the necessary costs of operating a site. Financial assurance mechanisms to provide for these costs should be established during the active operating period of the site, when revenues are still being received by the licensee, and he has access to financial resources. An applicant seeking a license for the disposal of low-level waste must estimate the costs of closure in order to provide for adequate financial assurances based on these estimates. Therefore, the amount of financial responsibility required of licensees will be consistent with the degree of risk associated with the closure and long-term care of the site. (Estimates of the costs of various potential expenses of closure and postclosure care of a site are presented in Appendix Q of the EIS.)

Meeting such a technical requirement for closure and active institutional care will involve a cost to the licensee. However, proper closure should help to prevent other costs, such as remedial costs, administrative costs to the regulatory agency, and environmental costs. For example, failure to provide for adequate financial assurances for closure could result in a situation where it is necessary for the responsible regulatory agency or the site owner to provide for final closure and stabilization at taxpayer expense. Any corrective actions would also need to be taken by the agency as well as the longer-term institutional control activities. Environmental costs that could be incurred if a licensee was unable to conduct final closure and stabilization could include increased potential for contamination of soil, air, and surface and ground waters. Adequate funds must be provided during operations to cover the costs for closure and for long-term care activities.

The need for stringent closure and long-term care financial regulations for low-level waste site licensees at the federal level has been voiced by a number of sources, including:

o The NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds provided a forum where NRC staff and state officials expressed their concern regarding the need for adequate closure and long-term care financing regulations for LLW sites. The majority of state officials felt that funds were not being collected at a sufficient rate to adequately provide for closure and long-term care of the sites.

- o In 1976, the GAO issued a report to Congress recommending that the federal government should establish criteria for long-term care and adequate funding of radioactive waste sites.

- o The National Conference of Radiation Control Program Directors has established Task Forces on Waste Management and Bonding. In their report, the Conference's Bonding Task Force developed general guidelines relating to bonding, and to perpetual care funds for the commercial waste burial grounds. The Task Force concluded that a review system should be instituted at both the state and the federal levels.

- o Public comments on the preliminary draft (dated November 5, 1979) of 10 CFR 61 have expressed the view that the Commission should develop adequate closure and postclosure care financial regulations for low-level waste sites. (See Section 6 of this appendix for a detailed description of these comments.)

- o The Commission has also sponsored regional workshops in Boston, Chicago, Denver, and Atlanta for the public and for representatives from industry, environmental groups, waste shippers and generators, and public interest groups, to review and comment on the preliminary draft financial assurance regulations in 10 CFR 61. Comments from these officials, as well as from other members of the public, strongly supported the need for financial assurance regulations, but also expressed the opinion that the Commission staff should modify the financial regulations in draft Part 61 with regard to (a) the types of costs to be recovered from LLW users through a long-term care fund, and (b) the parties responsible for paying for these costs.

1.2 Other Closure and Long-Term Care Funding Requirements

The Commission staff reviewed a variety of regulations in their analysis of funding requirements for a low-level waste disposal site (see Section 5 for a full listing of the financial assurance regulatory provisions reviewed by the staff.) These include:

- o Discussions with staff at the U.S. Environmental Protection Agency's Office of Solid Waste, who are working on financial requirements pertinent to RCRA and the "Superfund" Act (P.L. 96-510).

- o Discussions with staff at the U.S. Department of Interior's Office of Surface Mining who were involved with the financial regulations for surface coal mine operations.

- o Discussions with staff at the U.S. Federal Maritime Commission who administer the financial regulations pertaining to water pollution.

- o Commission final Generic Environmental Impact Statement and regulations pertaining to long-term care requirements for uranium milling operations under NRC license.

- o Review of existing state regulations for long-term care funds.

Based on this review, the staff has been able to develop recommendations for financial regulations for closure and long-term care that build upon existing regulatory developments in this area.

1.3 Overview of Closure and Long-Term Care Financial Requirements

The recommended financial regulations for 10 CFR 61 have the purpose of assuring financing of disposal site closure and postclosure activities and also any long-term care that is necessary at the site. The two concepts of requiring short-term financial assurances for site closure and postclosure activities, and financial requirements for long-term care or institutional control are treated as separate topics in this discussion. In order to see how these two financial requirements fit into the overall activities at a disposal site, Table K.1 depicts the relationship of the proposed financial requirements to the life cycle of a near-surface disposal facility.

As used in this discussion, a short-term financial assurance refers to an arrangement intended to ensure that the disposal site operator is financially capable at all times for undertaking all required and necessary closure and postclosure activities. For a typical near-surface disposal facility, these closure costs are estimated by the staff to be between $1.0 to $3.0 million dollars, in 1980 figures. (See Appendix Q of the EIS for a fuller analysis of closure costs.) Currently, many states already require hazardous waste site operators to provide various types of financial assurances for closure. In their review of various financial assurances, the staff examined the following mechanisms: sureties, letters of credit, escrow arrangements, trust funds, certificates of deposit, cash deposits, deposits of securities, secured interests, and self-insurance. The discussion in Section 3 of this appendix presents the staff's assessment of different types of short-term financial assurance mechanisms by various criteria, and then recommends certain types of mechanisms.

Long-term care funding at a near-surface disposal site refers to the financing of any necessary maintenance, monitoring, and surveillance that may be required during the 100-year period of active institutional control after the disposal facility licensee's site closure and postclosure responsibilities have been fulfilled and the license is transferred to the site owner. The 100-year custodial period is the upper bound that the Commission considers feasible for active institutional control to be exercised. The landowner or custodial agency during this active institutional control period would physically control access to the site. Activities carried out during the active control period also include, but are not limited to, carrying out an environmental monitoring program at the site, periodic site surveillance, minor custodial care, and other requirements as determined by the Commission. The active institutional control costs include all necessary maintenance, surveillance, and monitoring costs deemed necessary at the site.

The staff currently lacks the authority to require the licensee to provide funds for long-term care (see Section 4). Therefore, until such time as the

Table K.1 Life Cycle Financial Assurances for a Disposal Facility

Time in Years	Activity	Form of Financial Assurance
1-2 years	Site Selection and Characterization	Licensee responsible for costs incurred
1-2 years	Licensing Activities	Licensee responsible for costs incurred including licensee fee
		Site closure plan including cost estimates for closure is submitted as part of licensee application
		Lease arrangement with long-term care arrangements for financial responsibility between licensee and state submitted to NRC for review for adequacy
		Licensee obtains adequate short-term sureties to provide for closure
20-40 years	License Issued; Site is in Active Operation; Waste Received	Short-term sureties in place for closure: NRC periodically reviews and requires updating to account for changes in inflation, site conditions, etc.
		NRC periodically reviews revisions to lease arrangements to ensure that arrangements for financial responsibilities for long-term care are adequate
1-2 years	Site Closure and Stabilization	Costs covered from short-term sureties, if necessary; otherwise, licensee performs activities
		Lease arrangement between site owner and operator for long-term care is still in effect
5-15 years	Observation and Maintenance	Licensee still responsible for all further costs during this period, with short-term financial assurances still in place.
100 years	License Transferred to Site Owner "Active Institutional Control Period"	Terms and conditions of lease are met, and either state or licensee provides funds to pay for all required and necessary activities of this period.

Commission receives this authority, the staff has recommended that the licensee submit a binding arrangement (such as a lease) between the licensee and the landowner (the state or federal government), which delineates financial responsibility during the 100-year institutional control period. (See Section 4 for a more detailed discussion of the various alternatives for active institutional control financial requirements.)

Further sections of this appendix will deal with the following subjects: Relation of Life-Cycle Activities at an LLW Site to Proposed Financial Requirements (Section 2), Short-Term Assurances for Closure and Postclosure (Section 3), Long-Term Funding Requirements (Section 4), Other Governmental Financial Requirements for Closure and Long-Term Care (Section 5), Public Comments Pertaining to Financial Requirements (Section 6), Background Reference Materials (Section 7), and a Bibliography (Section 8).

1.4 Staff Recommendations for Financial Requirements

Based on the analyses for operators of a disposal site, the staff developed the following technical criteria:

- o Each disposal facility applicant must provide evidence of financial responsibility for all operational and predictable site closure costs, and evidence of suitable arrangements for long-term care costs for up to 100 years.

- o The licensee has the responsibility for determining that all of the site-specific activities and resultant costs of closure and postclosure observation and maintenance are accounted for in the stabilization and closure plan. On reviewing the site application, the Commission would then determine that all necessary costs had been included in the plan.

- o Prior to startup of operation, the licensee must obtain a short-term financial assurance mechanism found acceptable to the Commission that is sufficient at all times to cover all costs of closure and postclosure care.

- o The cost estimates for closure and active institutional control at a disposal site used in arriving at the amount of financial responsibility should be flexible and provide for annual reviews to account for advances in state-of-the-art technologies, work already completed at the site, and changes in inflation.

- o With regard to developing regulations for long-term care, the staff is aware of the need to develop specific regulations that establish a long-term care fund to ensure that there are adequate funds for up to 100 years of active institutional control, including surveillance, monitoring, and required maintenance. Currently however, the Commission lacks statutory authority to require long-term financial assurances (see Section 4 for a more extended discussion). The Commission has recognized the need to receive legislative authority from Congress that would allow the Commission to explicitly require that a fund to provide for long-term care be established. However, until such time as the NRC is given this authority, the staff recommends that the staff carefully review a binding arrangement (such as lease agreement) between the license applicant and the site's landowner. This lease arrangement submitted to the Commission for review must demonstrate that one or the other (or both) of the parties to the lease is responsible for all necessary maintenance, monitoring, and surveillance for up to a 100-year period following closure at the site.

o Financial responsibility for cleanup of unanticipated long-term activities that are acts of God and that are not explicitly provided for in the lease, would be borne between the appropriate governmental agencies, and by the site owner. The staff feels it is the responsibility of the applicant, the regulatory authority, the land owner, and all other parties to the proceeding to review the lease at the time of the licensing hearing to ensure that the proposed lease arrangement provides for all of the possible site specific expenses that pertain to required and predictable activities at that particular site. In developing financial assurances for closure and for long-term care of disposal sites, the staff's recommendations are predicated on the assumption that no contingencies will occur at the site and necessitate remedial actions. Both short-term and long-term financial assurances provide for adjustments in the event of any required and predictable changes in site conditions, inflation, or technology. However, they do not provide for major contingencies that are an act of God.

Therefore, the Commission staff recommends that the proposed regulations include the following:

1. During the operating life of the disposal facility financial assurances will be required of the licensee to provide full coverage of the costs of closure, decommissioning, and decontamination of the site. The amount of funds to be insured by such arrangements will be based on licensee-submitted cost estimates that are approved by the NRC staff during the time of license review. The licensees' cost estimates shall take into account the total costs that would be incurred if an independent contractor performed the work. The terms of the financial assurance mechanism must be open-ended, and must be reviewed annually. Mechanisms for closure found acceptable by the staff include: (1) surety bonds, (2) cash deposits, (3) certificates of deposit (CDs), (4) deposits of government securities, (5) letters or lines of credit, (6) trust funds, (7) escrow accounts, and (8) combinations of the above, or such other types of arrangements as may be approved by the Commission. However, the staff finds that self-insurance, financial tests, and secured assets by an operator are not an appropriate financial assurance mechanism.

2. Prior to the issuance of a license, the terms and conditions of the lease (or other binding arrangements) between the licensee and the site's landowner will be examined by the NRC staff to ensure that provision has been made between the two parties so that sufficient funds are available to cover the cost of long-term surveillance, monitoring, maintenance, and all required and predictable site-specific activities for the active institutional control period.

2. OVERVIEW OF LIFE CYCLE ACTIVITIES AND FINANCIAL ASSURANCES AT A DISPOSAL FACILITY

The development of financial requirements for 10 CFR Part 61 is based on a scenario of the operating cycle of a low-level waste site that follows the sequences generally represented in Table K.1 of Section 1. It should be noted that although the appendix describes a generic burial ground, the precise actions that occur during the life-cycle of a disposal facility may be site specific. This section of the appendix characterizes the nature and extent of activities required during the life cycle of the disposal facility in order to provide a basis for the analysis of both short- and long-term funding issues. In order to trace the flow of costs, and the responsibility for these costs to the respective parties at a disposal facility, the following section will present the staff's scenario of activities occurring during the life cycle of a licensed low-level waste site.

Appendix Q of this EIS also provides a more detailed description of the typical life cycle costs at a disposal facility. In developing their scenario of the events, activities, and costs of a disposal facility, the Commission staff is aware of the limitations of forecasting possible scenarios and resultant costs, such as inflation for long periods into the future. Nevertheless, they feel that the financial regulations should still attempt to cover some of those future costs that can be reasonably predicted, so that the present generation of users of the site receiving the benefits of the site are financially responsible for them, and the public's health and safety is still protected.

Under the requirements of NEPA, the Commission is charged as a federal agency with the responsibility of conducting their activities so as to help the nation fulfill the responsibilities of each generation as trustee of the environment for succeeding generations. The intent of these financial regulations is to satisfy this goal by ensuring that the present generation of users of the site be responsible for the majority of cradle-to-grave costs of a disposal facility. The staff believes that the financial requirements for site closure and for the long-term care will lessen the probability that succeeding generations of taxpayers will have to be responsible for the costs of today's commercial applications of nuclear power or use of radiation and radioisotopes.

2.1 Site Selection and Characterization

During this period (estimated to last approximately 2 years) the applicant selects a region of interest, and then narrows down the possible sites to a proposed site. The applicant is responsible for all costs and will probably capitalize them, and pass them on at a later date to customers as a future business expense. The applicant's choice of sites during this period is also based on the performance objective of minimizing the need for long-term care at the disposal site.

2.2 Preoperational Phase

The applicant begins to develop data and makes overall plans for the facility. The applicant also starts to develop a preliminary site closure plan, based on the information about the geology, hydrology, and other characteristics of the site. A site utilization plan is prepared by the applicant that outlines how the applicant plans to use the site for disposal. The applicant must also have preliminary estimates of the expected cost for (1) closure (including personnel needs and materials and equipment needs), and (2) active institutional controls, including surveillance and monitoring by the site's custodial agency. As in the site selection activities, these expenses are probably capitalized by the applicant, and passed on at a later date to customers as a normal expense of doing business.

The license application provides financial proof that the applicant possesses sufficient financial resources to cover construction and operating expenses. At this time, the applicant also provides assurances that he or she will have sufficient funds to carry out closure of the disposal site. These financial assurances are based on costs estimated in an approved plan for site closure and stabilization.

In the license application, the site operator should also provide a copy of a binding arrangement (such as a lease) between the applicant and the site owner for Commission review and approval for adequacy to ensure that sufficient funds will be available to cover the costs for up to 100 years of long-term surveillance, monitoring, and custody. Either the licensee or the state must demonstrate in a lease or other binding arrangement that they have assumed financial responsibilities for up to 100 years of responsibilities after the site has been closed and the license transferred to the site owner.

2.3 Operational Phase

When a license is granted the licensee can begin work on the construction of the site. The construction and associated regulatory costs of inspection are all borne by the applicant and are again, probably passed on at a later stage to the customers during the operational phase.

During the operational phase, that lasts from 20-40 years, waste is received and the licensee or landowner (depending on the lease conditions) is responsible to ensure that procedures are in effect to ensure that recovery is being made for the closure and active institutional control costs. (These closure and active institutional control costs are based on estimates submitted by the applicant to the Commission during the initial license application.) Future funds for the "short-term" decommissioning activities are guaranteed by financial assurance mechanisms such as sureties, CDs, letters of credit, cash deposits, trust funds, or combinations of these mechanisms. Again, the regulatory goal during this operational stage is to ensure that the activities are conducted so as to minimize the need to conduct long-term and extensive maintenance after the site is closed, and also to develop requirements for long-term care to ensure that adequate long-term care funds are available.

During this phase of active operation, when wastes are being received for burial, some trenches are closed and stabilized. Records are kept of all repair work done to fences, trench caps, and site grounds due to erosion or subsidence. These records will later be used by authorities to determine future maintenance activities and their associated costs. During this period, if it is found that a particular site has special problems that require more closure or postclosure activities than was orginally planned for, then the Commission may authorize increases in the amounts required for collection of closure and long-term care funds. These increased costs for closure and long-term care to the operating company would be passed on to the users in the same manner as any other cost of doing business. During this period, if the licensee were to go bankrupt, the funds for closure would be protected. The short-term financial assurance mechanisms approved by the Commission would provide full coverage for the necessary closure funds.

2.4 Site Closure Phase

When the site is filled to capacity, it is closed. Approximately one year before anticipated closure, the licensee must submit a final site-closure and stabilization plan to the Commission for review and approval. When the plan has been approved its requirements must be met by the licensee for such activities as decontamination and dismantlement, final site contouring, and preparation for long-term care. The activities and expenses for these activities should be minimal, since the licensee has already worked continually during the operational phase to prepare the site for closure. Specific site problems would also be taken care of at this time.

At this phase in the life cycle of the site, no revenues are being received from users, since no wastes are being taken in and the site is either at or near capacity. The licensee will probably have collected a surcharge from the site users to cover costs and will also have a short-term financial assurance in effect. For long-term care he will have made financial arrangements with the site landowner (i.e., federal or state government). Since the licensee would have no revenues coming in, it is important that at the time of licensing all parties do a careful job of forecasting all closure activities, and also recognizing the impacts of inflation in calculating these figures.

2.5 Postclosure Observation and Maintenance Period

This stage occurs after the terms and conditions of the closure plan have been met. The licensee is still held responsible for the site during this period when the monitoring and maintenance programs continue and these activities are, in a sense a continuation of the closure and stabilization activities. This period of the site's life cycle would last approximately five to fifteen years, and during this period, it is anticipated that the licensee's activities and costs at the site would gradually taper off to the point where little or no maintenance would be necessary. Essentially, this period would be one of monitoring, which would enable the Commission staff to fully satisfy itself that all of the terms and conditions of the license had been fully met by the operator, and that the licensee was still under regulatory authority to correct any problems that might develop at this time due to subsidence. Again, the licensee would presumably be paying for these expenses from the fund that was collected earlier from a surcharge on the site's customers. If the licensee were to default at this time, the appropriate short-term financial assurance mechanism would cover these expenses. It is also important for the licensee to carefully calculate and provide for a thorough analysis of all costs that can be quantified for this period, and to include them into the fund. If significant unexpected expenses do develop during this period, then, as in the previous period, the government or the governmental body responsible for owning the land site would probably eventually be liable for these expenses.

2.6 Long-Term Care (Institutional Control Period)

After the postclosure observation period ends and conditions at the site have stabilized and all closure responsibilities by the licensee have been met, then the licensee is relieved of this responsibility and the license is transferred to the site owner. The new licensee is then responsible for maintenance, monitoring, and surveillance at the site. During this period, which should last approximately 100 years, funds for long-term care will be transferred to the new licensee and they are responsible to disperse the long-term care funds to take care of monitoring, inspection, and necessary maintenance costs at the site. (The collected long-term care funds were received from either the site owner or the site operator, depending on what arrangement was made in the lease.) Minor maintenance activities during the 100-year long-term care period are envisioned to consist of repair of fencing, upkeep of the site, such as revegetation, mowing the lawn where necessary, and any repair of trench caps, due to subsidence or other conditions. At the end of this period, in the unlikely event that any of the funds collected for long-term care remain, they then would be returned to the contributing party (i.e., the original licensee).

3. SHORT-TERM FINANCIAL ASSURANCE MECHANISMS FOR CLOSURE AND POSTCLOSURE OBSERVATION AND MAINTENANCE

3.1 Introduction

This section addresses short-term financing mechanisms that provide a means of guaranteeing the financing of closure, stabilization, and all other required closure and postclosure observation and maintenance activities at a low-level waste site. This short-term financial mechanism for closure activities is separate and distinct from "long-term" care financial arrangements that cover the active institutional control period, and are discussed in Section 4 of this appendix.

The staff recommends that operators of an LLW disposal facility obtain a short-term financial assurance mechanism that is in effect throughout the operating period of the site. The financial assurance must also be sufficient to cover all anticipated costs of closure, including decommissioning and decontamination of the above ground buildings, equipment, and facilities, as well as stabilization of the disposal site. The amount of funds to be provided are to be based on Commission-approved cost estimates in a Commission-approved plan for closure. Such a short-term financial assurance would provide sufficient financial capacity during the entire operating period to cover all costs of closure, and the financial assurances would remain in place until all necessary closure and postclosure care activities had been conducted.

The staff is sensitive to comments given to the Commission indicating a strong need to require disposal operators to possess financial assurances for closure (see Sections 1, 6, and 7 of this appendix). The staff believes that the closure activities at a low-level waste site must be conducted in a prompt manner in order to ensure that the public's health and safety is protected. The requirement for a financial assurance for closure can be viewed as a type of financial guarantee to ensure that in the event of operator default, there are funds available for closure.

This section of Appendix K will present the types of short-term financial mechanisms examined and found acceptable by the staff. The advantages and disadvantages of each mechanism are briefly discussed, and a staff position on acceptable financial assurances is presented. Because the primary function of this section is to present a broad evaluation of various financial assurance mechanisms, the section is written in general language. A regulatory guide will be issued by the staff at a later date and will provide more specific guidance on the format and content of the various financial assurances.

3.2 Eligibility

The short-term financial assurance requirements recommended by the staff for the draft regulation should be met by all private sector licensees. However, this financial requirement would not have to be met if the applicant is a government entity and has the taxing authority to raise revenues. However, the staff feels that certain public entities, such as public authorities that lack taxing authority, may have a degree of financial risk associated with their operations necessitating that they meet the proposed financial assurance requirements. Therefore, for these types of public authorities that lack taxing authority, the staff recommends that they be required to fulfill all of the terms and conditions for short-term financial requirements.

3.3 Closure Activities and Expenses

In order to provide some background to this discussion, a review of the pertinent closure and stabilization activities and costs at a disposal facility is necessary. Appendix E provides a detailed discussion of the life cycle activities at a reference LLW site and Section 2 of this appendix presents the proposed life cycle activities in a schematic fashion for a typical disposal facility. It should also be emphasized that the precise activities that will take place during the closure and stabilization phase at a disposal facility will be site-specific. The closure activities will mainly consist of dirt-moving operations, such as trench cap reworking, in order to prepare for long-term care. As indicated in Appendix Q, costs associated with final closure for a reference site are estimated to be in the range of $1.0 million to $3.0 million (1980 dollars).

Closure of a low-level waste site includes the final operational activities carried out at a disposal facility after completion of active waste receipt and disposal operations to:

1. Dismantle site structures;

2. Decontaminate site surfaces and remaining structures;

3. Conduct final closure and stabilization of the site (facility) and emplaced waste; and

4. Carry out any other activities to prepare the site for postoperational care and transfer to the eventual site owner.

The Commission staff assumes that the site closure and stabilization program required at a site will vary depending on specific site geology, hydrology, and climate conditions, as well as any arrangements that may have been concluded between the licensee and site owner. The operating history of the burial ground, as shown by records of maintenance, monitoring programs, site inventories, and anticipated future use of the site, will also be important factors in determining if revisions to the financial assurance are necessary, to be certain that these closure activities are properly carried out. The primary objective of closure and postclosure care activities is to leave the site in a condition such that the need for active, ongoing maintenance is eliminated after license termination, and only passive care is required.

The licensee must develop site closure and stabilization plans and ensure that the site is prepared for transfer to a custodial government agency. After the active period of operation of the site, the site operator's responsibility and authority for possession of buried wastes at the site continues until the Commission finds that the site is ready for transfer to the custodial agency. The remainder of this section will review the various types of financial assurance mechanisms and delineate those assurances deemed adequate by the staff.

3.4 Short-Term Financial Assurance Mechanisms for Closure and Postclosure

Short-term financial assurance mechanisms refer to arrangements intended to ensure that the licensee is financially responsible for undertaking all required closure and stabilization activities at a low-level waste disposal site. As used here, the concept of financial assurances (short- or long-term) does not include any requirements for third party liability coverage for damage to people or property resulting from operation of the facilities. Rather, the staff is establishing various financial assurance criteria which will ensure that the sites are properly closed, stabilized and monitored for up to 100 years.

There are a wide variety of short-term financial assurance mechanisms to assure that proper closure occurs that could be investigated; however, the short-term financial assurance mechanisms considered by the Commission staff for the purposes of this regulation include:

1. surety bonds, obtained from a surety company
2. escrow arrangements between the bank, the government, and the licensee
3. trust funds arranged between the government, a financial institution, and the licensee
4. certificates of deposit to a state or federal agency
5. cash deposits to a state or federal agency
6. deposits of securities to a state or federal agency
7. pledges of securities and liens against properties of the licensee
8. letters of credit from a financial institution
9. self insurance by the LLW operator
10. financial tests of the LLW operator's assets.

These types of financial assurances are presently being used, or provision has been made for their use by state and federal government agencies, for the chemical waste, uranium milling, low-level waste, and surface coal mining industries. The staff did not explicitly review a financial assurance consisting of a sinking fund for closure based on surcharges collected from waste generators, since at this time, the Commission lacks the statutory authority to impose a surcharge or other tax on waste generators. However, this financial assurance mechanism has been traditionally employed at low-level waste sites, and states having authority to permit this may wish to consider a sinking fund in combination with some other form of short-term financial assurance mentioned above.

3.4.1 General Criteria for Financial Assurances for Closure and Postclosure

The staff's development of these technical criteria for financial assurances for closure was based on recognition of the importance of balancing the need to require sufficiently stringent assurances with the economic consequences of such an alternative. For example, in the staff development of criteria that the financial assurance mechanism must be fully funded prior to startup of operations, the staff also considered the less stringent approach of allowing the funds to build up over the life of the site. The staff was aware that this second approach would have been a lesser financial burden to the operators, since it would not require them to set aside a large sum of capital. (The EPA staff's development of RCRA regulations also noted that the fully-funded approach placed a tax burden on the operator, because current tax laws do not allow this fund to be considered a deductible expense, since no expense occurs in a tax sense, until the funds are used for closure.) Nevertheless, the staff also realized that allowing a closure fund to build up over the life of the site could well result in having an inadequate fund available in the event of premature closure of the site, with the result being that the taxpayers would then be financially responsible. In weighing these two equity alternatives, the staff concluded that the fully-funded approach to closure offered the most reasonable assurances that the license be fully responsible for the costs of closure.

- Regardless of the financial assurance used, the licensee's cost estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the stabilization and closure activities.

- The financial assurance mechanism must be full funded prior to the start of operation, to provide full assurance regardless of whether closure occurs as was originally planned, or else occurs prematurely.

- The face value of the short-term financial assurances must be at least equal to the cost estimates submitted by the licensee in the approved plan for site closure and stabilization.

- In order to avoid unnecessary duplication and expense, the Commission may accept financial assurances that have been consolidated with financial arrangements established to meet requirements of other federal or state agencies and/or local governing bodies for these decommissioning, decontamination, reclamation, and closure activities, provided that such arrangements are considered adequate by the staff to satisfy these requirements, and that the portion of the financial assurance that covers the closure of the site is clearly identified and committed for use in accomplishing these activities.

- The licensee's financial assurances should be reviewed annually by the Commission to assure that sufficient funds are available for completion of the closure plan. At that time, the amount of coverage is also required to be adjusted to recognize inflation, changes in engineering plans, previous activities already performed, and any other conditions affecting closure costs.

- Regardless of what portion of closure is phased through the life of the operation, or if it takes place at the end of operation, an appropriate portion of coverage has to be retained until final compliance with the closure plan is determined. This will yield an assurance that is at least sufficient at all times to cover the costs of closure of the site prior to the next license renewal.

- The term of the financial assurance mechanism must also be open-ended (i.e., not cancellable), unless the licensee can demonstrate that another arrangement would provide an equivalent level of assurance. This assurance could be provided with a financial assurance that is written for a specified period of time (e.g., five years) and will be automatically renewed, unless the party administering the financial assurance notifies the beneficiary (the Commission or the state or regulatory agency) and the principal (the licensee) at some reasonable time (e.g., 90 days) prior to the renewal date of their intention not to renew. In such a situation the financial assurance still exists, and the licensee would be required to submit a replacement assurance within a brief period of time to allow at least 60 days for the regulatory agency to collect.

- The Commission will allow the licensee to terminate the financial assurance mechanism after a finding that all licensee conditions have been met.

- Proof of forfeiture must not be necessary to collect the financial assurance for closure, so that in the event the licensee could not provide an acceptable replacement surety within the required time, the surety will be collected automatically prior to its expiration. The conditions described above would have to be clearly stated on any financial assurance instrument that is not open-ended, and must be agreed to by all parties.

With respect to Commission-licensed facilities, the implementation of this requirement to provide financial assurances to cover costs associated with closure activities could occur in several ways. The Commission could directly administer the financial arrangements, or a state could administer them. The staff believes state administration would be appropriate where an existing state agency already handles the financial assurance arrangements for hazardous sites or for mining activities. All of the states have the authority to impose financial requirements as an exercise of their general police power to protect the public health and safety. This would be true whether or not the state is an Agreement State under the provisions of the Atomic Energy Act of 1954, as amended.

3.5 Criteria for Evaluating Financial Assurance for Closure and Postclosure

Financial assurance mechanisms to cover costs associated with closure were evaluated by the staff on a specific set of criteria. The primary factor considered by the staff in evaluating the various mechanisms was the degree of assurance provided by each method to ensure that funds were available for closure costs at the disposal site. Other criteria the staff considered include:

- o Degree of security (or level of difficulty) in obtaining funds in case of default.

- o Amount of regulatory staff administrative time and expense required to implement and monitor the financial assurance.

- o Amount of staff effort required to evaluate assets of the licensee.

- o Cost of financial assurance mechanism

A description of the various financial assurances considered by the staff in their review follows.

3.6 Financial Assurance Alternatives for Closure

3.6.1 Surety Bonds

A surety bond provides a cosigner on an obligation. The surety bonding relationship is essentially a three party relationship in which the surety company, for a fee, promises to the obligee (the NRC) that the principal (the licensee) will perform specified activities (in this case, all closure and decommissioning activities). If, as a result of this obligation, the surety company incurs a loss, it can sue the contractor to recover its loss. The surety company takes on a possible liability for a profit. Like insurance, a premium is paid to the surety company by the insured or bonded entity (such as the disposal site operator). However, a surety company does not expect the principal to default, and if default does occur, then the surety has the right to receive reimbursement from the principal for the obligations met. If a bonded operator were to default on his obligation to carry out closure activities, then the bonding company must provide the remainder of the guaranteed funds to the holder of the bond (the regulatory or other suitable government agency) to have the work done. On the other hand, upon successful completion of closure activities by the operator, the bonding arrangement can be terminated and the bonding company is then released from its obligation.

When surety companies provide coverage for closure by issuing a bond to the applicant, they check the financial strength of the applicant. They will likely require a licensee to provide some form of collateral in order to write performance bonds. The amounts required of the operator will vary, depending on the business history and credit rating of the applicant. Generally, the types of collateral required by a surety company include letters of credit, corporate stocks, and certificates of deposit. The applicant then has to maintain a commitment of collateral value sufficient to cover a certain percentage of the face value of the surety bonds.

The cost of a surety bond is dependent on the type of required activities covered by the bond, but fees on premiums generally range from between 1.0 and 1.5 percent of the face value of the bond. The surety company also needs to have sufficient assets to provide for possible default.

Surety companies have the option of filing with the U.S. Treasury, which sets limits on the face values of bonds. This limit of a surety bond is generally 10% of the surety's capital surplus. Since filing with the Treasury represents a form of certification, the Commission staff recommends that surety bonds only be accepted from companies listed in the Department of Treasury circular #570, entitled "Surety Companies Acceptable on Federal Bonds" (published annually) and only for an amount that is within the company's single policy limitation as identified.

Surety companies are generally regulated by state laws that are designed to ensure that the surety company is solvent and has assets of a certain minimum amount. Additionally, state regulation of sureties involves assessment of financial management practices, including examination of whether the sureties are diversified in their lines of credit.

All bonds specify the terms and conditions of their guarantee, including terms of default. Generally, contract bonds contain provisions that state what constitutes a default. Some events used are: inadequate performance, such as abandonment of work or bankruptcy proceeding. If an owner defaults and has not completed the required and necessary decommissioning activities, then a claim can be made by the NRC. If a default occurs, then the surety will first examine its defenses against liability before making payment to the obligee, the NRC. If it is determined that a default has occurred and that no defenses exist, then the surety company is responsible for bringing the permitted work to completion.

According to a draft study done by the International Research and Technology Corporation (IRT) in 1980 for the EPA, defaults on surety bonds occasionally wind up in court. Therefore, surety bonds may be more of a problem to collect than certificates of deposit, which would not become involved in such litigation. However, the Commission staff investigation has shown that collection records on these forfeitures in the coal industry has been satisfactory.

Several commenters on the NRC uranium milling regulations and EPA solid waste regulations expressed doubt that the surety industry would provide bonds to the hazardous waste industry with open-ended terms. The Surety Association, a trade association that recommends bonding rates to members, has, in the past, told the NRC they doubted there would be any market in the U.S. for such corporate surety bonds with open-ended terms. However, a brief review of other hazardous waste facilities indicates that there is some market demand for this type of insurance. The Federal Surface Mining Act of 1977 requires mining companies to obtain a performance bond certifying that the mining activities will be conducted subject to license requirements. The reclamation operations are done as an ongoing operation of the site, rather than waiting until all of the land is strip mined. Performance bonds of strip mining have been written for time spans paralleling the 30-year periods anticipated for bonds of some typical facilities. The Environmental Protection Agency has also proposed the use of surety bonds for coverage of closure of hazardous waste sites in their proposed RCRA regulations. It is possible that the

Department of Interior and the EPA regulations for sureties may stimulate a demand for this type of surety mechanism.

If one assumes that the surety bond would be obtained in the site's first year of operation and continue for five to fifteen years after the active operating lifetime, the licensee would be responsible for the cost of the bond for a total of 25-35 years. In some cases, the bond may have to continue for longer than five years after the end of operation. However, once operations cease and the site is closed, and the license transfered to the site owner, the licensee would terminate the bond.

The major advantages of the surety bonding mechanism are:

- Staff administrative effort associated with a bond, exclusive of the effort related to forfeitures, would be minimal. A document sent to the federal or state regulatory agency from the surety company and filed with the license application assuring that the surety was properly certified by the appropriate agency licensing sureties, would be all the effort necessary to implement this bonding mechanism. Amendments to the amount of the bond would also involve minimal correspondence with the surety company. Bonding companies thoroughly screen the credit record of the companies they bond, so the agency does not have to conduct a financial analysis of the operator's operations.

- A rider to an existing bond, or the purchase of a new bond, would be sufficient to adjust the amount of the bond to account for inflation or required changes in closure activities.

The major disadvantages of this bonding mechanism are:

- Obtaining funds from the surety upon default may be more difficult than under some other alternatives, such as trustee funds or cash deposits.

- The cost of obtaining a surety bond is higher than some of the other surety mechanisms.

- There is some doubt that surety companies are willing to provide sureties for waste disposal businesses for a 20 to 30-year time period. In informal conversations with surety officials, the staff found that officials were not certain of the extent to which surety companies are willing to become involved in this type of coverage.

3.6.2 <u>Cash Deposits</u>

A cash deposit is another method of assuring closure, whereby an amount at least equal to the estimated cost of closure is deposited into a special account that could be held by a government agency. Use of the funds in this account would be restricted to covering the costs of closure and postclosure. If the operator were to default, then the state or federal government could withdraw the funds from the special account and arrange for the necessary closure work to be completed by either themselves, by the site owner, or by an independent contractor.

Some advantages of this method are:

- o There is no difficulty in obtaining funds in case of default by the site's owner, since the special deposit fund could be set up so that it was controlled by the government agency.

- o There is no problem in asset evaluation.

Some disadvantages of this method are:

- o If the funds are deposited into a special account with the U.S. government, then no interest can be paid on these funds. Therefore, there is a lack of productive assets, and additional funds would have to be paid into the fund to account for losses in inflation.

- o Management of the funds by the government would require periodic review and evaluation by the staff to ensure that the funds were adequate to reflect changes in inflation, engineering plans, activities performed, and other site-specific conditions affecting costs.

3.6.3 Escrow Funds

An escrow fund is another method of assuring funds for closure. Under such an arrangement, cash or marketable securities in an amount equal to or greater than the estimated costs of closure are deposited into a special account held by a financial institution. An escrow serves as a receptacle for the deposit of goods or property until the licensee completes closure activities. The institution holding the funds is the depository, and an escrow agreement sets out the terms and conditions by which the materials can pass to either party. Depositors, however, are not trustees. An escrow that functioned as an assurance for closure and postclosure costs would involve a binding agreement with terms and conditions that would specify that upon failure to meet prescribed closure activities, the fixed amount necessary for all closure activities held in escrow would pass to the appropriate state or federal government. Conversely, upon a finding that closure had been satisfactorily conducted, the escrow arrangement would be terminated and the amount in it returned to the licensees; or the escrow could be set up such that the escrow funds could be returned to the grantor or licensee as closure costs are completed by the licensees.

Generally, administrative fees are charged for the management of an escrow account and will vary depending on the degree of activities, not on the amount of funds. Banks may set a flat fee for a certain number of transactions; other banks will set their fees for managing an escrow account on the basis of each investment or transaction. One of the big differences between a trust and an escrow fund occurs because a bank managing an escrow generally will perform only those activities specified in the agreement. Generally, the escrow fee is less than the fee for trusts. Use of an escrow fund would require that the amount established in an escrow fund would be sufficient at all times to pay a fixed amount for closure in the event of licensee default. As with all other financial assurances, the types of investment made would have to be examined on a periodic basis by the NRC staff to ensure that the funds in the escrow account keep pace with inflation. In the unlikely event that any excess amounts were earned, they would be returned to the licensees. Use of the funds in this account would be restricted to covering the cost of site decommissioning and closure. If the operator were to default, then the state or federal government could withdraw the funds from the special account and use the funds to conduct closure activities.

Some of the advantages of this method include:

- There is minimal difficulty in obtaining funds in case of default by the operator since the special deposit account is controlled by an escrow agreement between the government agency and the licensee that clearly stipulates the terms and conditions for the use of funds.
- The staff does not need to manage the funds; they are managed by professional staff.
- No problem of asset valuation exists in this alternative.
- The funds can be invested in long-term securities, thus protecting their value from erosive inflation.

Some disadvantages of this method are:

- Fees for managing an escrow account are based on the amount of activity in the account, not on the amount of principal or income. Therefore, if frequent adjustments are made to the amount in the escrow, to account for inflation or changes in site conditions, then there may be more costs to the operator.
- In the past, escrow accounts were short term in nature, and problems may arise with a commercial escrow agent managing a fund for 20 or more years.
- Like certain types of trusts, escrow accounts must pay taxes on their income at the full federal tax rate.

3.6.4 Trust Funds

A trust fund is a well-established mechanism for holding property and applying it, or income from it, to a particular purpose. The concept of a trust fund to provide for closure of a disposal facility is not new. In 1980, a trust fund to provide for closure costs was proposed by Chem-Nuclear, Inc., for their LLW disposal facility in Barnwell, South Carolina. The RCRA financial requirements being developed by EPA for operators of hazardous waste sites have also recognized the trust mechanism as an acceptable type of financial assurance mechanism for closure.

A trust is an arrangement whereby one party holds and may even manage funds or property for the benefit of another. In this case the beneficiary of the trust fund would be the state or federal government. The trustee of the closure trust would be a bank or some financial institution. The terms of the trust would define the investment responsibilities of a trust. The trustee has possession of the property or funds placed in trust by the party who created the trust (in this case, the state or federal government). The trustee is said to have the legal interest in the funds, since he has control over it, can sue to protect it, and is responsible for its preservation. The beneficiary cannot use the trust funds, but is entitled to those benefits (such as income) derived from the trust, and intended for him under the terms of the trust. The trustees are under a fiduciary duty to comply with the terms of the trust and, unless the trust provides otherwise, are liable for breaches of this duty.

Like other financial assurances, the necessary amount in the trust fund is determined at the time of the license review, and the trust must include the full costs of closure at all times. The trustee is then required to turn over a fixed amount in the event of licensee default. A trust fund's revenues could be used, if the NRC determines that it is necessary. Once this determination has been made, the NRC could (1) arrange for closure activities and bill the costs to the trust; (2) do the closure itself, and then apply for reimbursement from the trust, or (3) require that the trustee undertake all of the approved closure activities, and then pay for them out of the trust funds.

The Internal Revenue Service has developed a series of rulings to control the use of trusts since they are popular mechanisms for tax avoidance. The closure trust fund is functionally equivalent to simply placing certain money in savings accounts and then accumulating the interest from it for a period of years. In that situation, a draft study done by IRT for the EPA found that the owner of the account is taxable on the income from the account. A closure fund would be established in a lump sum by the licensee at the outset of site operation, and would consequently be returned to him, plus its appreciated value at the end of site life, assuming that the closure activities were in compliance with the site closure plan.

As part of the license application, a site operator must estimate closure costs in an approved site closure and plan. If the licensee defaults at the site before closure can be properly conducted, then the government, as trustee, could require that the money in the trust fund be used to meet the requirements of the site closure plan for the site. If closure activities were properly conducted, then the trust fund could be set up in such a way as to include reimbursement for closure costs as they are incurred, rather than waiting until all closure activities were finished.

A trust fund can contain more than just cash. Property such as securities or government notes can be placed in trusts. However, if cash substitutes are allowed within the framework of trusts, then the function and obligation of the trustee must be redefined, and they may possibly charge more for their services. If other types of assets were allowed, the trust would have to agree to pay the NRC a stipulated cash amount.

Although, the NRC is responsible for determining if the funds in the trust are adequate, the staff also realizes that it is not difficult to make the trustee responsible for merely maintaining the funds at a certain value. However, giving the trustee the power to demand a supplementation of funds from the owner/operator is more difficult. One possibility would be to have the trust commit the licensee to provide a sum sufficient to close the site instead of stipulating a flat dollar amount, and then bind the licensee to provide more, if necessary, at the request of the trustee. The NRC staff could determine that the fund or assets were inadequate over time, and require the owner/operator to add assets to the trust, leaving the trustee with only the administrative responsibilities for the trust, or the regulations could be revised to allow for periodic adjustments in the cost estimates and the trust, in order to reflect changes at a site or in the technical requirements of the regulations.

If assets other than cash are deposited in the trust fund, it may be necessary for the trustee to buy and sell securities with the approval of the NRC staff, or to take other steps to manage the assets in order to maximize their value. However, unless specified in the terms of the trust, a trustee usually must invest under a reasonably prudent investor standard, as defined by statute or case law of the jurisdiction where the trust is located. The trustee has a fiduciary obligation to honor the terms of the trust, and this standard of fiduciary duty is so strict that most trustees will only accept carefully defined responsibilities.

In addition to cash, trusts may also hold securities, stocks, bonds, certificates of deposit, savings accounts, real property, or commercial buildings. According to one report that consulted with bank officers, the type of assets that trusts were asked to hold were not of as much concern as the quality of the particular asset. The bank officers' concern lay in the degree of uncertainty of the risk they were assuming. The report also found that the prospect of holding assets in trust for 30 years or longer did not concern the trust officers of the banks interviewed. In fact, trust officers pointed out that because of the duration of the site life, and consequently the trusts, trust accounts would be preferable to escrow accounts that traditionally are used for, though not limited to, short-term agreements.

The NRC could consider any individual for the position of trustee in addition to financial institutions, who can succeed in obtaining insurance for the position. This type of insurance is currently available and is commonly obtained by banks and by other financial institutions.

Trustee fees may be relatively constant, but are normally defined as a percentage of income or principal, with the result being that it cannot be known with certainty if the income from the trust is not certain. Trustee fees can range from between 1% and 2% annually of the amount to be managed in the trust, and may also vary according to the degree of management responsibilities given to the trustees.

The burden of a trust fund to the licensee may be quite high because of income taxes. If a trust is a conventional private trust, then payments to the trust are not tax deductible, and the taxes on income from the trust are paid by the trust at the tax rate applicable to trust income. The resulting cost to the licensee could be significant. To the extent that closure costs are a significant fraction of the total costs of operating a site, the cost of taxes to the licensee will increase the economic impacts of closure.

In conclusion, the staff finds the trust fund to be an adequate financial assurance mechanism. However, care must be taken to ensure that the licensee put up an amount sufficient to cover closure over a given period and make annual payments to this fund to cover inflation and any changes to the site. However, the high cost of this financial assurance mechanism, relative to other alternatives, necessitates a close analysis by all parties involved.

Some of the advantages of this method are:

- A trust arrangement can give a careful delineation of the responsibility of all parties to the trust.
- The trust fund can accept noncash securities such as stocks, bonds, CDs, or savings accounts.
- Trustees with financial experience can invest the funds in a manner to keep pace with inflation.

Some of the disadvantages of this method are:

- If noncash assets are placed in a trust fund, then the trust fund will require more care and review by the trustees and the regulatory authority.
- If the trustees are responsible for maintaining the fund at a certain amount, it may be difficult to set up an arrangement whereby they have the authority to call for additional money from the licensees.
- If noncash assets are placed in the trust, then the trustee may manage their sale and purchase and some risks are taken. However, the trustee must be committed to yielding a specified dollar amount.
- Depending on how the trust is set up, taxable income from the trust may have a tax imposed on it by the IRS that the grantor (the site operator) must pay.

3.6.5 Certificates of Deposit (CD)

Another possible mechanism for assuring closure activities is through the use of certificates of deposit (CDs). Generally, certificates of deposit may be issued by any bank. Cash or securities are deposited by the site owner with the bank, and a certificate of deposit is issued, made payable to a government agency. Only the government agency could cash the certificate. The CD is then cashed if the operator is unable to complete decommissioning activities.

Again, the amount of this surety is adjusted over time to reflect inflation. At the end of operation, if the operator satisfactorily closes the site, then the government agency would return the CD to the operator.

Some advantages of this method are:

- There is minimal difficulty in obtaining funds in case of default by the operator, since the certificate is held by the government agency.

- The fee for purchasing the certificate of deposit is small.

Some disadvantages of this method are:

- More effort is needed to adjust the amount of the fund than is required under some other alternatives. (A new certificate of deposit must be purchased.)

- Certificates of deposit result in a significant amount of corporate funds being unavailable for the business.

3.6.6 Deposits of Securities

Using this scenario, the licensee would be responsible for depositing securities to the appropriate government agency with a face value equal or greater to the highest cost of closure at the site. Theoretically, the securities referred to here could be of several different kinds, including long-term U.S. bonds; municipal bonds; or corporate securities.

Some of the advantages of this method include:

- There is little difficulty in obtaining the funds if the operator defaults, as the government agency already has access to the necessary funds.

- The operator incurs no additional expenses (such as an annual premium for a surety bond) beyond the face value of the securities and any required transfer fees.

Some disadvantages associated with this method are:

- Unless a trust administrator is used, the responsible government agency must play a more active role under this method than under most other alternatives. It must hold the funds, distribute dividends from the securities to the operator, determine security values, and exchange securities for other securities as the operator desires or as the market demand changes.

- The values of the securities will fluctuate as the market demand changes, thus causing additional administrative time to be spent to ensure that the proper amount is maintained in the fund to keep pace with inflation.

- o Some administrative time is required of the staff for adjusting the amount in the account. This involves contacts with the operator for additional securities, and fund administration time.

3.6.7 <u>Pledges of Securities and Liens Against Properties of the Licensee (Secured Assets)</u>

These types of secured interest are interests in personal property or fixtures of the operator that gives the holder of the interest the right to possess the assets to ensure payment of an obligation. These financial assurance mechanisms are similar to self-insurance except that the licensee pledges certain assets which could be used by the Commission to perform closure and postclosure activities in the event of licensee default. A secured interest gives the government agency the right, in the event of default by an operator, to take possession of the assets and sell them in satisfaction of the claim. In most cases where a secured interest has been properly created, the holder of the interests has first claim or priority over these assets, if the operator goes bankrupt. The secured assets may be repossessed by the secured interest holder, and proceeds from the sale of the assets are not required to be shared with other creditors in bankruptcy proceedings. Pledges of securities would require the Commission to possess collateral and have the staff make periodic assessments that the value of the securities was sufficient to meet closure activities. Furthermore, the status of a securities pledge in the event of financial failure of the pledger is uncertain and can differ substantially with variations in state law.

Liens against land and real property would also require the Commission staff to undertake periodic assessments to ascertain that changes in inflation, depreciation policies, etc., had not reduced the ability of the liens on the land and real property to pay for closure of the site. Additionally, liens would require the Commission to first foreclose and then sell the property before funds would be available for closure activities at the site. An EPA review of this financial assurance mechanism has also found that liens also suffer from an uncertain status in the event of financial failure of the owner.

Some of the advantages of this method are:

- o Few additional expenses are incurred by the operator. The only costs involved would be those legal costs associated with preparation of documents.

- o There is no loss of productive use of corporate assets. The collateral that is used as the secured interest remains with the operator.

Disadvantages of this method are:

- o A significant amount of adminstrative staff time is necessary. Staff effort is necessary to establish a security interest by completing all the necessary paperwork and renewing the collateral to ensure that their value is sufficient to pay for closure costs.

- When it becomes necessary to adjust the amount of the fund, additional assets must be added to or withdrawn from the agreement. Again, staff time is necessary to reevaluate the value of the operator's assets.

- Significant problems can occur if the government finds it necessary to obtain funds for closure in the event of licensee default. Other creditors may also place liens on the company's assets, and the legal process may considerably delay recovery of the assets, as well as resulting in significant staff time and expense.

3.6.8 Letters of Credit

Irrevocable letters of credit are another short-term financial assurance alternative to ensure that sufficient funds are available for closure and postclosure expenses at a disposal site. Traditionally, letters of credit have been primarily used in international trade. In using this method, the operator would apply to a bank for the issuance of a letter of credit that commits the bank to pay the beneficiary (the state or federal government) if the letter of credit comes due. A letter of credit consists of a bank's document written on behalf of the party (licensee) that would give the governmental agency the right to draw funds from the issuing bank upon the presentation of papers in accordance with the letters of credit. The cost of a letter of credit is based on the face value of the amount, the amount of time required for coverage, and the risk to the bank. Banks issuing standby letters of credit charge fees on between .5 to 2% of the face amount of the letter of credit.

Guidelines for a letter of credit are found in regulations issued by the Department of Treasury, Comptroller of the Currency (12 CFR §7.7016). A national bank can issue letters of credit permissible under the Uniform Commercial Code on behalf of its customers. Guidelines stipulate that letters of credit should meet the following conditions met:

1. Letters of credit should conspicuously state that it is a letter of credit.

2. The bank's undertaking should contain a specified expiration date, or be for a definite term.

3. The bank's undertaking should be limited in amount.

4. The bank's obligation to pay should arise only upon the presentation of a draft or other documents as specified in the letter of credit, and the bank must not be called upon to determine questions of fact or law at issue between the account party and the beneficiary.

5. The bank's customers should have an unqualified obligation to reimburse the bank for payments made under the letter of credit.

Originally, letters of credit were "documentary"; they were used to finance a shipment of goods and require the beneficiary of the letter to present documents, such as invoices, before obtaining payment under a letter of credit. For the purposes of this regulation, the staff considers this type of letter of credit is not an appropriate mechanism for assuring closure at a disposal site. Rather a "clean" letter of credit, which doesn't require shipping or invoice documents before drafts on letters are paid, would be the most appropriate form of letter of credit for disposal facility licensees. The guarantee or standby letter of credit is a clean letter of credit that is written to financially protect the beneficiary from failure on the part of the account party to meet the terms of a contract between them. This type of credit is then irrevocable for the life of the credit.

An acceptable letter of credit for the purposes of this regulation would specify the NRC as the party who may draw upon the fund in the amount of the most recent closure care estimate required to be made in the site closure and stabilization requirements. The letter should also specify that the NRC can draw upon the funds behind the credit, following the finding of a violation of the closure/postclosure care requirements. Letters of credit can also be created to reflect the regulation's requirement for periodical adjustments to reflect changes in inflation.

Open-ended letters of credit are traditionally not written. However, staff research indicates that the same level of assurance provided by an open-ended surety mechanism can be obtained with an automatically renewed, irrevocable letter of credit. A letter of credit with such a clause provides that the credit is for a definite period with a renewable term. If the letter is not extended by the bank, then the NRC is empowered to draw against the credit. If the letter of credit were written for a specified period of time (e.g., one year), it would have to state that the bank agreed to automatically renew the letter of credit upon expiration unless the bank notified the beneficiary (the regulatory agency) and the principal (the licensee) some reasonable period of time (e.g., 90 days) prior to the renewal date of their intention not to renew. In such a situation the requirement still exists and the licensee would be required to submit another financial assurance in order to allow at least 60 days for the regulatory agency to collect.

The staff finds that a necessary condition of this financial assurance is that proof of forfeiture must not be necessary to collect. The conditions described above would have to be clearly stated on any letter of credit that is not open-ended, and must be agreed to by all parties. Such an arrangement demands efficient procedures for collection.

In order for an operator to obtain a letter of credit, he must apply to banks or financial institutions that will issue one. The operator would often be required to give the bank some type of security interest in his property. In the alternative, he may need to supply capital to the bank to ensure that he will not default.

Fees for issuing a letter of credit are generally lower than those for trusts or bonds. Guarantee letters of credit have fees ranging up to 2% of the face value of the amount.

Some of the advantages of this method include:

- o This method requires only a minimal amount of time, on the part of the government agency, to administer. The letter of credit could be filed with the license.
- o There is no problem of having to evaluate assets for the government agency; this activity is performed by the bank. NRC simply receives the letter of credit for the amount required.
- o The administrative fees for this type of financial assurance are generally less than for trusts or bonds.

Disadvantages of this method include:

- o More administrative time would be necessary to adjust the amount of the letter of credit. This would require the issuance of a new letter of credit from the bank.
- o A direct cost is involved to the operator for obtaining the letter of credit.

3.6.9 Self Insurance by the LLW Site Operator

As used in this analysis, self insurance means an arrangement whereby the operator agrees to perform the closure and postclosure activities, and finance the activities out of his own resources, such as cash working capital. In effect, it is an alternative involving no additional assurance other than the licensee's legal obligation to perform closure activities, which are required as a condition of the license. The legal obligation pursuant to the license exists regardless of any separate contract or lease, whereby the operator agrees to perform closure.

The primary problem of using self insurance occurs when the licensee may not have sufficient funds to meet his responsibilities, at a time when no revenues are arriving from the operation.

One advantage of this alternative is:

- o There is no cost to the licensee.

Some disadvantages of this method are:

- o In case of default, the government agency would have to obtain a legal judgment based on its contract with the licensee and then would have to execute its judgment if the operator has assets out of which the judgment can be satisfied. The staff believes such a regulatory approach is not acceptable.

3.6.10 Financial Tests

Financial tests are another variation of self-insurance, which require the licensee to develop a set of criteria showing that he has sufficient unencumbered assets to provide for closure. These assets are not pledged or retained for closure. Rather, financial tests would enable the Commission to monitor the financial health of the licensee's operations. In the event of deteriorating financial conditions of the licensee, he would then be required to establish another form of financial assurance.

There are a variety of financial tests which could be used by the regulatory staff to ascertain that the licensee has sufficient financial health: net working capital, net worth, a review of the total liability to net worth ratio, the current or quick ratio, and the age of the firm. A brief description of these different types of financial tests follows.

Net Working Capital

Net working capital is the difference between current assets and current liabilities. Provision of sufficient net working capital would enable the regulatory agency to determine that the licensee has sufficient unencumbered assets available for closure. Net working capital would have to be greater than the potential closure expenses because of the quickness with which the net working capital can decline. One study reported by IR&T of 32 failed firms during the period of 1964 to 1970, found that net working capital for the average firm declined 33 percent between the fourth and third years prior to failure and disappeared entirely between the third and second years to failure. This information suggests that if this financial test were used, there would be a need for net working capital in excess of the actual closure costs.

Net Worth

Net worth is the difference between the total assets and total liabilities, and is equivalent to the equity of the owner. Net worth would have to be equal to or greater than the potential closure expenses.

Total Liability to Net Worth Ratio

This test would serve to exclude firms which are large enough to meet a net worth test but so highly leveraged as to present potential insolvency problems. (A highly leveraged firm has a relatively high fraction of its capital structure in the form of debt.)

Current or Quick Ratio

The current or quick ratio is the ratio of current assets to current liabilities. The quick ratio is the ratio of cash, current receivables, and marketable securities to current liabilities. This financial test differs from the current ratio chiefly by the exclusion of inventory. A firm with a large net working capital could still have serious financial problems if its current or quick ratios were relatively small.

Age of the Firm

The age of the firm is another financial test that could be used to predict the likelihood of insolvency of firms. For example, one study referenced in the IR&T report mentioned that in 1978, 53% of all business failures were firms which had been in existence five years of less.

One advantage of this alternative is:

- o Financial tests are an advantageous form of financial assurance for the operator, since they require no use of assets.

Some disadvantages of this alternative are:

- o Financial tests provide no protection that funds will be available for closure and postclosure care. Rather, financial tests serve as a stop-gap measure by which the regulatory agency determines if the operator's business is sufficiently strong to pay for closure activities. If the operator's operations are failing, then the regulatory agency would require the licensee to obtain another form of financial assurance. However, if a firm were in this position, then it probably would not be in sufficient financial health to obtain other adequate financial assurance mechanisms. For example, surety companies would probably not be interested in covering a company who could not meet the financial tests required by a federal agency. In such a case, the licensee would have to use a trust fund, deposit of securities, or some other form of financial assurance, which he may not be able to afford if in such a precarious financial position.

- o The use of financial tests also imposes a tremendous administrative burden on the licensing staff. As a result, the regulatory process may be lengthened as the staff is forced to evaluate various financial tests of the companies' financial stability. In conclusion, the staff feels that financial tests fail to provide a sufficiently stringent degree of protection, and therefore, they cannot recommend the use of this financial assurance mechanism for closure.

3.6.11 No Financial Assurance Requirements for Closure and Postclosure Care

Another regulatory alternative for short-term care would be for the regulatory agency to not establish any funding requirement on waste licensees for financial responsibility for closure and postclosure care. With such a scenario, the custodial care regulatory agency or the site owner would be responsible for all costs incurred during closure and postclosure. The staff did not consider this alternative for long-term care, since some forms of financial assurance for closure and postclosure care are already being implemented at existing LLW disposal sites. The Commission staff has also received comments on the need to establish financial responsibility for short-term closure and postclosure care activities for low-level waste sites. Based on these findings, the staff has determined that a regulatory approach of not requiring short-term financial assurances for closure of a site is not acceptable.

3.6.12 Other Short-Term Financial Assurances

3.6.12.1 Surcharge on Waste Generators and Collection of Funds Into a Sinking Fund

Requiring a licensee to impose a surcharge on a cubic foot or meter basis on the users of the site to recover closure expenses is a mechanism that is currently in use in several states with LLW disposal sites. The Natural Resources Defense Council has also previously requested the NRC to require a surcharge on a capacity basis to be imposed on users of disposal facilities. The staff recognizes the merit of such an approach from an equity basis. The use of a surcharge deposited into a sinking fund has been used as a collection method by several states to ensure that sufficent funds are available for closure. The burden of financial responsibility for closure is borne by the waste generators who use the waste disposal service. Nevertheless, there are several reasons why the staff cannot recommend this mechanism's use.

First, a sinking fund builds up funds gradually as revenues are received, and over the life of the site there is a high probability that there will not be sufficient funds at its inception to account for the full costs of closure. Such a mechanism would not guarantee that the full costs of closure were available at all times to account for closure. (This problem could be alleviated by simultaneously requiring another form of financial assurance on the remaining balance of closure funds.) A second reason why this financial assurance mechanism is not acceptable is because the Commission currently lacks the statutory authority to require licensees to impose a surcharge or a fee per unit volume of waste. Establishment of an earmarked fund would also require Congressional authorization. In 1978, the NRC staff responded to a petition for rulemaking by the Natural Resources Defense Council that called for the NRC to establish a special fund based upon a cubic foot charge. In their response to the petition, the staff noted that a federally mandated fee per unit volume of waste that is not a product of the landlord/tenant contract (i.e., a lease) would be, in essence, a tax that requires legislative enactment. Based on landlord/tenant (state or federal government/site operator) contracts authorized by state law, the states containing commercial burial sites have collected disposal fees from the site operator on a capacity basis. However, for the reasons stated above, a financial assurance requirement consisting of a surcharge as a means of collection cannot be imposed at the federal level.

Since the NRC currently lacks the authority to require the operator to establish a surcharge on waste generators, the staff has not conducted an analysis of using a sinking fund based on a surcharge. However, the use of a sinking fund based on a surcharge on a capacity basis may be an appropriate way of building up funds for closure if a guarantee on the balance of closure funds is implemented to ensure that, at all times, there are sufficient funds to pay for closure. (For those Agreement States that may wish to consider the imposition of such a financial assurance system, the staff has calculated estimates of these surcharges using the Decost Computer Program and these estimates are available upon request.)

3.6.12.2 Closure Pool

Another possible variation for assuring adequate financial funds for closure involves the development of a pool of closure assurance funds. This approach was included in the Battelle Study on Decommissioning. Disposal facility operators (and possibly, operators of other fuel cycle facilities) would make payments to such a fund. An independent "Closure Assurance Agency" would be chartered to retain and invest the funds and perhaps oversee activities and disperse payments to those conducting the activities. The pooling of closure funds into such a centralized agency could help to ensure closure performance even if a particular facility operator defaults. The agency would act in a fiduciary capacity for the public. Payments and interest received by the stewardshop entity would be exempt from federal income tax because the entity is a creation of the U.S. or a state government and is an exempt scientific entity.

The pool would be obligated to pay for closure of a site if the operator defaulted on performance of required closure activities. However, setting the appropriate premiums would be difficult, since the pool administrator would have to estimate the likelihood of nonperformance or partial performance, and then calculate the magnitude of the fund required to complete the closure activities. Such an assurance would have to be established by the federal government and would require Congressional action. Therefore, since the Commission currently lacks the statutory authority to create such a financial assurance mechanism, such a short-term financial approach is not discussed further.

3.7 Conclusions and Staff Recommendations

There are a number of financial assurances to provide adequate public protection to ensure that funds for closure exist in the event that the LLW site operator defaults. The alternatives that the staff finds acceptable on a generic basis for an LLW disposal facility licensee are: surety bonds, trust funds, escrow arrangements, cash deposits, certificates of deposit, deposits of government securities, and irrevocable letters of credit. These alternatives were all found to be acceptable by the staff because without incurring a significant administrative burden, they can be structured in such a way that there is a high degree of assurance that funds are available to ensure a proper closure. Although the administrative burdens associated with the various mechanisms the staff has approved do vary to a certain extent, this variance is not expected to be significant. Approving a range of satisfactory alternatives allows the operator flexibility in selecting the mechanism that best suits his needs. In addition, this range allows the use of a combination of financial assurance mechanisms.

While the other financial assurance mechanisms discussed earlier may be acceptable in certain cases, with the exception of self insurance, the staff finds that they are not acceptable on a generic basis. Plans for alternative financial assurances not discussed here would have to be evaluated on a case-by-case basis.

Therefore, with regard to short-term financial assurances for closure and postclosure, the staff developed the following criteria for operators of a disposal facility:

- o Each applicant must demonstrate adequate financial resources to cover the estimated costs of conducting all licensed activities over the planned life of the project including ensuring that sufficient funds will be available to carry out final site closure, postclosure care, and stabilization activities.

- o Prior to startup of operations, the licensee must obtain a short-term financial assurance mechanism found acceptable to the Commission that is sufficient at all times to cover all costs of closure and postclosure care, and must be based on a Commission-approved plan for closure and stabilization.

- o The short-term mechanism must be in effect throughout the operating period of the site.

- o The licensee's costs estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the decommissioning and closure activities.

- o The face value of the short-term financial assurance must be at least equal at all times to the cost estimates submitted by the licensee in the approved Plan for Site Closure and Stabilization.

- o The financial assurance mechanism must be full funded prior to the start of operation, to provide full assurance regardless of whether closure occurs as was originally planned, or else occurs prematurely.

- o The licensee's cost estimates must take into consideration the total costs that would be incurred if an independent contractor were hired to perform the decommissioning and closure activities.

- o The licensee may use one or more of the mechanisms allowed in the regulation to meet these requirements.

- o The financial assurance mechanism must be open-ended and cannot be cancellable.

- o Proof of forfeiture must not be necessary in order to collect the financial assurance mechanism. If the licensee cannot provide an acceptable financial assurance substitute within the required period, then the mechanism will be automatically collected prior to its expiration.

- o The Commission will allow the licensee to terminate the financial assurance mechanism after a finding that all license conditions have been met.

- o The licensee must annually adjust the amount of funds provided by the financial assurance mechanism to account for changes in inflation, site conditions, and technology.

- o Flexibility be allowed regarding the specific financial assurance mechanism used, stating that:

  - cash deposits
  - trust funds
  - surety bonds
  - escrows
  - certificates of deposit
  - deposits of government securities, and
  - irrevocable letters of credit

  or combinations of these financial assurances would be acceptable on a generic basis, and that that other financial assurance mechanisms would be evaluated on a case-by-case basis for acceptability.

- o Factors should be stipulated that must be considered in setting up the financial assurance, including:

  - inflation;

  - term of the mechanism (i.e., the term of the assurance must be open-ended and remain in effect until the regulatory agency releases it on satisfactory completion of closure);

  - an adjustment provision that requires a periodic review of adequacy of the financial assurance mechanism. The face amount should be adjusted to recognize any increases or decreases resulting from inflation, changes in engineering plans, activities performed, and any other conditions affecting costs. This will yield an assurance sufficient at all times to cover the costs of closure and postclosure.

Based on these findings, the staff has determined that an LLW disposal licensee provide financial assurances for closure and postclosure care. The costs developed for a typical facility described in Appendix E of the EIS includes the costs for a financial assurance for closure as part of the base case costs.

As was mentioned earlier, the NRC lacks the authority to require the licensee to establish a surcharge on waste generators to pay for the costs of closure (and postclosure) activities. Some states, however, may have this authority, and they may want to implement this funding mechanism. Section 4 of this appendix provides a brief description of aspects a state might wish to consider in establishing a sinking fund based on a surcharge for either a closure or long-term care fund.

4. LONG-TERM CARE (ACTIVE INSTITUTIONAL CONTROL) FUNDING REQUIREMENTS

4.1 Introduction

The staff recommends that a low-level waste license applicant should provide the NRC with a binding arrangement (such as a lease between himself and the state), which specifies that adequate funds for up to 100 years of long-term care of the closed site will be provided by either the applicant or by the governmental body owning the land. The staff considers this approach necessary in order to ensure that these activities will be performed promptly and in a manner that will protect the public health and safety. Such activities would be site-specific, and include monitoring, surveillance, and any necessary maintenance. The lease must also take into account the cost of inflation over that period. The Commission would also periodically review this lease to ensure that the terms and conditions are kept current to reflect changes in inflation and specific site conditions. Examples of specific lease forms that the staff finds acceptable will be presented in a forthcoming regulatory guide issued by the Commission.

The Commission currently lacks the statutory authority to require the licensee to develop a long-term care fund. (See the discussion of SECY-78-613 in Section 8 of this appendix for a fuller analysis of this issue.) The staff is cognizant that establishing a regulation that required a licensee to establish a long-term care fund would be a stronger regulatory approach than the more indirect method of reviewing a lease or binding arrangement that delineates financial responsibility for this period. However, until such time as the Commission receives this statutory authority, the Commission staff considers that requiring the licensee to submit a binding arrangement or lease for review by the Commission is the most appropriate regulatory approach, based on current authority. Such a lease arrangement is currently used at all six sites to delineate the roles and responsibilities between the landlord (state or federal government) and the tenant (the operating company) with regard to the long-term care of the site.

4.2 Need for Requiring Financial Assurances for Long-Term Care

A review of the history of commercial low-level nuclear waste sites in this country (see Section 6 of this appendix) indicates that there has been continuing concern by the public and by regulatory authorities over long-term financial responsibility for low-level waste disposal sites. In addition to questions over the equity issues of who pays for long-term care, the government and the public are concerned that funds be readily available in order to ensure that the public's health and safety are continually protected. The controversy over long-term care at the Sheffield, Illinois low-level waste disposal site that ensued between the licensee and the state of Illinois is a contemporary illustration of the dilemma that exists in this area. Another event that has highlighted this controversy concerning the adequacy of long-term care funds occurred at the closing of the reprocessing plant at West Valley, New York. The GAO report to Congress on this site found that the "perpetual" care fund was inadequate to cover the long-term associated costs of the site. The GAO report also found that the recommendations raised larger policy issues "concerning whether or not, and to what extent, the federal government should provide financial assistance to the nuclear industry by taking over the cost of managing activities in the back end of the fuel cycle."

Based on these and other considerations, the Commission staff has been careful to include requirements for financial guarantees for long-term care in the proposed low-level waste regulations, in order to ensure that the public health and safety is protected.

Existing state financial requirements for care of a disposal site after the license is transferred have frequently been referred to as "perpetual care arrangements." They are based on the same concept as scholarships, research endowment funds, or perpetual care funds for cemeteries. Funds are invested and a return is earned on this principal. When the amount of interest earned is adjusted by the annual inflation rate, then the net rate of return is determined. This net return is then used to pay for various activities, such as research, scholarships, maintenance at a cemetery, or conversely, surveillance, monitoring, and maintenance at a low-level waste disposal site. If the net rate earned on the principal is larger than inflation, then the principal is left intact, and the principal can be invested again and again (in "perpetuity") to fund these various activities through the return earned on the invested principal. However, if the interest rate earned on the principal is less than the inflation rate, or large, extraordinary expenses develop that were not originally planned for, then the principal must be used if the activities are to be paid for. In that case, the principal is eventually reduced to zero, and the "perpetual" care fund is of short duration.

4.3 Shortcomings of Existing Financial Mechanisms for the Recovery of Long-Term Care Funds

The actual experience with "perpetual" care funds at low-level waste disposal sites (henceforth referred to as long-term care or institutional control funds) has not been good. A staff review of the existing low-level sites (see Section 6) found that the majority of state officials indicated that the "perpetual" care funds were inadequate to cover the costs of long-term care activities. This shortcoming of long-term care funds at disposal sites occurred because of several factors. First of all, conservative investment policies, traditionally adhered to by state-investing agencies, mandated that the funds be invested in low-risk investments that traditionally do not earn high rates of return. Frequently, returns on these less risky investments have not kept up with inflation. (In one case, the collected funds for long-term care were never even invested or put in an earmarked fund, thereby guaranteeing that no funds would be available for long-term care.) Second, the continued high inflation rates in the last decade have resulted in a devaluation of the funds. Additionally, state authorities in charge at the time the funds were set up, and who were responsible for establishing the amount and surcharge required to collect the long-term care fund, were frequently unaware of the magnitude of the types of remedial activities required for long-term care at the low-level waste disposal sites, with the result being that not enough funds were collected to take care of water-management problems. Because of these shortcomings, the long-term care funds have been inadequate to meet the necessary long-term care activities at low-level waste sites.

In specifying the types of costs to be considered in the establishment of a long-term care binding arrangement, the Commission staff has patterned their suggested requirements after portions of recommendations made on this topic by the 1976 Task Force Report on Bonding and Perpetual Care of Licensed Nuclear Activities (see Section 9 of this appendix). The report recommended that a perpetual care trust fund for long-term care be legally established, which drew interest adequate to pay the costs of monitoring and maintaining the closed site. The perpetual care trust fund was to be earmarked and be limited to monitoring, maintenance, and other perpetual care activities at the radioactive waste burial site.

The staff does not recommend the use of a "perpetual" care financial arrangement for LLW disposal sites. Rather, they believe there should be a limited financial responsibility for long-term care for a period of up to 100 years of active institutional control. To the extent that the licensee and the licensing authority have correctly estimated the types of activities necessary during this period, along with their resultant costs (adjusted for inflation), then the long-term care funding mechanism should be adequate to properly handle the known and predictable expenses of this 100-year period. Beyond the period of 100 years, no expenses have been calculated for inclusion into the determination of active institutional control responsibility.

4.4 The Active Insitutional Control Period

The first 100 years of a low-level waste disposal site that occur after the site is closed and the license is transferred to the site owner is known as the active institutional control period. Activities carried out during this period include surveillance to physically control access to the site, environmental monitoring, and minor maintenance. During this period, the staff envisions there will be no major maintenance necessary at the site if it has been properly sited, designed, operated, and closed.

4.5 Types of Funding Arrangements for Active Institutional Control

There are a variety of long-term financial assurances that have been used by regulatory authorities to provide for long-term care (including surveillance, maintenance, monitoring, and all required and predictable activities) at a low-level waste disposal site. For example, several of the states currently require their licensees to collect a specified surcharge from their waste generators who use the site. The funds collected from these long-term care surcharges are then deposited into an earmarked state treasury account, or sinking fund, where they are invested to keep pace with inflation. If such a sinking fund were used, in order for the Commission to assure itself that there was protection to assure that funds for long-term care were available, a sinking fund would have to be combined with a performance bond on the unpaid balance. For example, suppose the Commission determined that $10 million in

1980 dollars were necessary for long-term care. During the first year of operation, the licensee might collect $.5 million from surcharges which he would then deposit into a sinking earmarked fund. During that year, they would then be required to post a bond for $9.5 million. In the second year of operation, assume that $10 million is deposited into the sinking fund. Then the licensee would have to have a performance bond of $9.0 million, and so on. Such a long-term care fund could be set up in two ways. First, a fund could be established on a "perpetual" basis where the funds earned each year from the invested principal are used to pay for long-term care costs. As long as the interest on the invested principal earned more than the inflation rate, there would be sufficient funds for postclosure care. The Uranium Mill Tailings regulations issued by the NRC in 1980 made provision for the development of a perpetual care fund for long-term perpetual care at decommissioned tailings sites. In the Generic Environmental Impact Statement on Uranium Milling, developed in conjunction with these regulations, NRC staff determined that funds should be provided by each mill operator to cover the costs of long-term monitoring. A one-time charge adjusted by changes in the Consumer Price Index (to be equivalent to $250,000 in 1978 dollars per site) is to be levied on mill operators before the termination of a license. The charge is to be paid to the federal government unless the state in which a mill is located chooses to take custody of the site. If the long-term monitoring charge is paid to the federal government, it would then be deposited in the General Treasury fund of the United States, as opposed to a special earmarked fund that might be established.

A second way that a long-term care fund could be set up is by the development of a fund for a finite period of care, such as a 100-year period. The funds would not be available in perpetuity, but rather for only a specified time. The principal amount (as well as return on this principal investment) of funds would be drawn on over the 100-year period to pay for all necessary long-term care, so that only a small amount of the principal and interest is left at the end of the 100-year period.

Another type of financial assurance for long-term care that has been proposed by some parties is the development of a federally administered perpetual care program to which all disposal facility operators would be required to contribute. Using this scenario, the federal government would be responsible for administering a radioactive "Superfund," that is similar to the fund being developed by the federal government based on P.L. 96-510. Proponents of this funding mechanism argue that, since burial sites serve national and not state needs, the citizens of individual states should not be required to bear the cost of major contingency actions for long-term care activities at these sites. The 1977 NRC Task Force Report on Review of the Federal/State Programs for Regulations of Commercial Low-Level Radioactive Waste Burial Grounds came to a similar conclusion. This report states "it appears desirable and equitable for the federal government to assume responsibility for long-term care of the sites, since the states generally do not have the resources to assure adequate care under a variety of contingencies," and also since the sites serve regional needs. However, this type of pooled risk long-term care mechanism would require enabling legislation from Congress, since the NRC currently lacks the authority to establish any type of postclosure care fund, let alone a shared risk process.

As has been demonstrated, a variety of long-term financial assurance mechanisms exist to provide for funding active institutional control activities such as surveillance, monitoring, and any necessary maintenance at a disposal site. However, because of a lack of enabling authority, the Commission staff can only require licensees to be party to a lease or other binding arrangement with the site's landlord in order to establish that full financial responsibility for long-term care care has been delineated between the two parties. The Commission staff is proposing this regulatory approach for long-term care at LLW sites until such time as the Commission has enabling legislation.

4.6 Types of Active Institutional Control Costs

What types of long-term care costs for the 100-year active institutional care period for a low-level waste site should be included in the lease arrangement? A variety of studies have been performed that have analyzed types and estimates of costs for long-term care at a low-level waste site. Appendix Q of the EIS provides a discussion of these studies and cost estimates that were developed. A discussion of inflation and interest rates is also provided, and recommendations for these variables are made in that appendix for the purposes of this regulation. The staff considers that responsibility for the following types of costs should be delineated in the lease or binding arrangement between the license applicant and the landowner of the low-level waste disposal site: surveillance; monitoring; and all required and necessary maintenance activities that the Commission deems necessary to protect the public's health and safety and the environment. Table K.2 is excerpted from Appendix Q of the EIS and presents a range of costs in 1980 for 100 years of long-term care activities for a range of different scenarios at a reference low-level waste facility.

Table K.2 Range of Long-Term Care Costs for 100 Years of Active Institutional Control at a Low-Level Waste Disposal Site (1980 Dollars)

Scenario	0-10 years	11-25 years	26-100 years	Total cost, 100 years
Low	$150,000/yr.	$63,000/yr.	$51,000/yr.	$6,270,000
Medium	$302,000/yr.	$150,000/yr.	$88,000/yr.	$11,870,000
High	$440,000/yr.	$302,000/yr.	$150,000/yr.	$20,180,000

4.6.1 Contingency Costs

The concern for ensuring that responsibility for unanticipated contingency costs is delineated during the long-term care period is especially great for disposal sites because of the long time period during which administrative controls may need to be maintained after the license is terminated. (As used in this discussion, the term "contingency" cost refers to those types of unanticipated long-term care costs that were not included in the original delineation of costs at the site.) However, it is extremely difficult for forecasters to project the frequency and severity of contingencies that might occur during this long of a time period, as well as estimating the costs necessary for the resultant remedial actions at such a site. At this time, the staff has not made a projection of these contingencies. Nevertheless, the staff believes that it may be appropriate to prepare a site-specific assessment based on information developed during the site's operating period, and if the results suggest that certain occurrences have a reasonable certainty of occurring, then the financial responsibility for their resultant costs should be included in the specifications of the binding arrangement or lease for that particular site.

With regard to this issue of who should bear the financial burden of long-term care contingency costs, the Battelle Northwest Laboratories (BNWL) study on Decommissioning a Low-Level Waste Burial Site (See Section 9 of this appendix) concluded, "in practice, it seems likely that the financial burden of unanticipated contingencies after burial ground closure will fall on the state and/or federal government." The study continues by pointing out that since some parties may argue that, since the buried waste originated from throughout the country, the burden for these types of long-term contingency costs may logically fall on the federal government. If this conclusion is followed, the report then argued that one possible solution might be for the federal government to formally assume an insurer's role for unanticipated contingencies and collect premiums as a surcharge.

The authors of the BNWL study also noted that "There is a possibility that the former site operator can be required to assume the burden for contingencies after closure. However, none of the existing license agreements appear to provide for this. In the absence of a contractual agreement, the operator who has relinquished the site could only be forced to assume the burden of contingencies if negligent burial practices can be shown. Even this possible solution may not be available if a cause of the action is initiated after the statute of limitations has expired. The odds are also high that the company may no longer be in business over such a long-term period."

Based on the previous experience gained from existing low-level waste disposal sites, the Commission staff believes that new sites can be licensed that will continue to adequately protect the health and safety of the public when closed. However, the staff also recognizes that in spite of the experience gained by the low-level waste disposal industry, shippers, packagers, and state and federal regulatory agencies, the history of closed low-level waste disposal facilities is insufficient to allow the staff to fully assess the possible long-term contingencies over a 100-year period. Uncertainty does exist about the types of activities and the costs that would be required over a long time period after a low-level waste site is closed and the license is terminated.

The staff considers that some of the uncertainty over financial responsibility for long-term care at an LLW site can be reduced at the time of licensing, when (a) the applicant demonstrates that the proposed site can be sited, designed, constructed, operated, and closed such that the need for long-term active maintenance is eliminated and (b) the licensee assesses what types of events might occur and what their impacts on a waste disposal site would be (e.g., long-term drought cycles, or long-term excessive moisture cycles). These considerations of possible contingency activities would have to be done on a site-specific basis during the licensing process. The Commission staff recognizes that it is unreasonable to expect the present generation of users of a site to pay for a worst-case scenario of long-term care expenses at that site, when the chance that such an event would occur is minimal. The Commission staff is unaware of any other regulated industry that must provide total costs for such activities that are remote, occur after the license is terminated, and are not easily subject to calculation of risk. Nevertheless, the Commission staff has concluded, based on the comments it has received on the draft, and also from the experience of other agencies in the area of long-term care funds, that it is appropriate that the lease be site-specific with regard to provision for possible long-term care costs.

Several participants at the LLW workshops also pointed out that if the risk of having remedial situations develop in a decommissioned low-level waste site were nonexistent, there would then be no need to have a long-term care inspection and monitoring program at the site. (In their development of the proposed regulations, the NRC staff has recommended that a monitoring and surveillance program be conducted after the site is closed.) As stated earlier, these long-term care activities can be minimized by requiring the licensee to site, design, operate, and close the site in such a manner so as to eliminate the need for active maintenance activities after the site is decommissioned. However, the staff feels that even the presence of such a performance objective in the regulation does not relinquish the Commission from their regulatory responsibilities to ensure that care is taken of the site after the license is terminated. The Commission staff feels that part of this long-term care responsibility should include a monitoring program to determine if unanticipated circumstances occur at the site that would require remedial action. Unexpected remedial costs do not refer to ordinary cost overruns that occurred during long-term care activities.

What will be the financial impact on waste generators at a low-level waste site requiring a long-term care fund? As was mentioned earlier, although the Commission does not have the authority to (a) require that a surcharge or other fee be required of waste generators in order to collect for either closure or for long-term care or (b) to actually require the LLW operator to establish a long-term care fund, nevertheless, the financial burden of long-term care traditionally has been placed on the users of the site. The proposed regulations only require that a binding lease between the licensee and the landowner be established in order to ensure that adequate funding be available for long-term care. The mechanics of collection are left up to the licensee and to the landowner. However, for the purposes of illustration, if the current state government practices of imposing surcharges on a capacity basis for long-term care on waste generators are followed by the licensee, then an estimated surcharge can be calculated. Charges for a long-term care surcharge can be computed based on assumptions made about the return on capital, the rate of inflation, the annual costs of surveillance, monitoring and maintenance, and the annual and total capacity of the site. The Commission staff has developed a computer program that will use the above figures to calculate the total amount and surcharge necessary to develop a long-term care fund, as well as the required surcharge on a cubic-foot basis. Entitled DECOST, (NUREG-0514), the program is flexible and can calculate costs under varying economic and planning conditions, and present results in either constant or inflated dollars.

4.7 Impact of Proposed Financial Assurance Requirements

The staff has determined that it is necessary to provide financial assurances for up to 100 years of active institutional control in order to protect the public's health and safety. The alternative of not requiring such a financial assurance for long-term care could result in a situation where the federal government and the taxpayers of the state where the site is located would be financially responsible for the long-term care costs of surveillance, monitoring, maintenance, and any remedial action at a site in the event of licensee default. Such a situation would result in an adverse impact to the taxpayers of the region and alleviate the users of such a site from bearing financial responsibility for long-term care. The staff has, therefore, recommended that the license applicant provide evidence of financial assurances for long-term care at the low-level waste site.

4.7.1 Conclusions

The Commission staff has found it necessary to require financial assurances for up to 100 years of active institutional control in order to protect the public's health and safety and the environment. The costs to be considered in the development of such a long-term care fund include surveillance, maintenance, monitoring, inflation, and all other activities deemed necessary by the staff.

Currently, the Commission staff lacks the regulatory authority to require that a license applicant develop a long-term care fund that would provide financial responsibility for up to 100 years. However, until such enabling legislation is received by the Commission, the staff feels that the methods discussed above will give the Commission staff the ability to determine that financial responsibility for 100 years of long-term care at an LLW site is met. Such a regulatory review would be done by examining the terms and conditions of a lease or other binding arrangement that would be provided by the applicant. The lease would have to ensure that either the site owner or the applicant is responsible for all of the previously mentioned long-term care costs. The Commission would also periodically review the binding arrangement to ensure that the lease was updated to account for changes in inflation and for changes in required maintenance activities. Thus, the costs for 100 years of institutional control have been incorporated into the costs for the reference facility, and corresponding alternatives have also been analyzed. The actual costs of long-term care, however, will vary depending upon the level of activities required under varying disposal facility conditions. In recognition of the need for establishing financial responsibility for long-term care, state authorities at each of the existing LLW sites have made provision for accruing these funds. Therefore, the reference facility described in Appendix E includes the costs for long-term care. The staff assumes that these funds for active institutional control would be obtained through a surcharge based on waste received at the facility. These monies obtained from the surcharge would then be placed into an interest bearing account.

5. OTHER GOVERNMENT REQUIREMENTS FOR CLOSURE AND LONG-TERM CARE FUNDS

A variety of state and federal agencies have developed closure and long-term care for financial requirements for operators of hazardous (both chemical and radioactive) operations. State experiences with financial requirements for disposal sites have shown that these financial requirements for closure and long-term care have not been adequate to fully pay for closure and long-term care of the site. Some of the reasons for this lack of complete financial assurances for closure and long-term care costs include the following: failure to consider inflation; failure to include changes in technology and standards; failure to include recognition of changes in site conditions; and failure to develop an earmarked, separate fund for the collection of these fees. This appendix provides a brief review of governmental experiences with financial requirements for closure and long term care costs for hazardous waste sites. The scope of the EIS serves to indicate that there is a strong need for the federal government to develop requirements for financial regulation in 10 CFR 61 to ensure that the costs of closure and long-term care activities are met in order to protect the public's health and safety.

5.1 Illinois

The Sheffield disposal site is regulated by both the state and federal governments. The site was originally opened in 1967 and received a license from the AEC. The NRC currently regulates the possession of byproduct, source, and special nuclear material at the site. The Illinois Department of Public Health owns the 20 acres used for burial and regulates possession of naturally occurring and accelerator-produced materials at the site. Financial requirements for perpetual care that exist are found in a lease agreement between the site operator (now U.S. Ecology, Inc., formerly Nuclear Engineering Company (NECO)) and the state. The original terms of the lease called for the operator to pay 5 cents annually to the state for each cubic foot of radioactive waste. At the time the original lease was executed (1966), the state did not have an earmarked or state fund for these collected monies. Funds collected for perpetual care and maintenance prior to October 1976 were deposited into the general treasury of the state and are not now available for closure and post-closure activities. In 1978, the lease was amended so that U.S. Ecology had to pay a perpetual care and maintenance fee to the state in the amount of 10 cents per cubic foot of all radioactive waste disposed of at the Sheffield site. The state of Illinois also enacted legislation to develop an earmarked fund for these fees. The Illinois General Assembly recognized that sites used for the disposal of radioactive waste would represent a continuing and perpetual responsibility in the interest of the health, safety, and general welfare.

Fees collected after September 1976 for long-term care were deposited in the state treasury and set apart in a special fund known as the Radioactive Waste Site Perpetual Care Fund. Monies from the invested funds were to be used by the Director of the Department of Public Health (now the Department of Nuclear Safety) to monitor and maintain the site. However, as of July 1, 1981, there was only approximately $40,000 in the fund.

The Sheffield site was closed in the spring of 1978, when NECO filled the last licensed burial trench. NECO withdrew their NRC license application for renewal in December 1978. In March 1979, NECO notified the state of Illinois and the NRC that they were unilaterally terminating their state and NRC licenses. NRC took action to require NECO to continue their responsibilities and obligations under their NRC license. The state of Illinois also brought suit to order NECO back to the site on the grounds that a public health hazard existed at the site due to their abandonment and existing site conditions. A state court injunction was obtained, ordering NECO back to the site. An agreement was reached between NECO and the NRC requiring NECO to act as licensee until the termination of their NRC license was settled before the Atomic Safety Licensing Board.

At the present time, final closure of the site and the conditions for termination of their NRC license are being litigated before the Atomic Safety Licensing Board. The state court case is also continuing in an attempt to settle the closure requirements before the state license and lease is terminated with NECO. Additionally, the state of Illinois has brought a suit to rescind the deed by which the state had become owner of the site.

The Illinois long-term care fund illustrates the problems that develop when the collected funds are not turned over to an earmarked fund, but placed in the general fund. The fund is currently inadequate to pay for any long-term care of the site.

5.2 Nevada

The Beatty, Nevada site was opened in 1962 and is operated by U.S. Ecology (formerly NECO). The site was originally licensed by the AEC, but is currently licensed by the state. The land where the site is located was originally owned by the state and subsequently leased to U.S. Ecology. In an NRC Task Force Study in 1976 (NUREG-0217), the state government has indicated to NRC staff that their earlier provisions for perpetual care funds for the site were inadequate, and state government officials also questioned whether the state had sufficient financial or technical resources if a major problem occurred at the site. Recently, however, the state has taken measures to ensure that a larger amount of funds will be available for closure and postclosure care activities. In 1977, the state of Nevada enacted Senate Bill No. 38, which revised the radiation protection regulation, as well as calling for the development of a long-term care fund for the LLW disposal site. The Act revised Section 5, Chapter 374 of the state of Nevada, 1961, and created a Radioactive Materials Disposal Fund in the state treasury. Fees are deposited in the Radioactive Materials Disposal Fund and are invested until the amount remaining in the fund is sufficient to carry out long-term care activities.

The State Board of Finance is authorized to invest any amount of money in the Radioactive Materials Disposal Fund in excess of $5,000 in short-term obligations. Upon the advice of the Director that it is necessary or advisable to convert all or a part of the obligations into cash, the State Board of Finance is to effect the conversion to the extent necessary, and the monies are to be redeposited in the Radioactive Materials Disposal Fund.

Monies in the Radioactive Materials Disposal Fund can be used for any expenses necessarily incurred by the Director of the Department of Human Resources in carrying out the provisions of the act. This would include administrative and regulatory expenses in amounts authorized by the legislature and the costs of providing protection resulting from the termination of any lease or agreement that is necessary in the interest of public health and welfare.

The lease has recently been updated. The revised lease agreement provides for a surcharge of $0.25 per cubic foot of radioactive waste buried (up from $.07 per cubic foot in 1976). The revenues derived from the burial fees are maintained in an escrow fund and are dedicated to perpetual care and maintenance of the site as well as contingencies.

The amounts established for the disposal or burial of low-level radioactive waste or chemical and toxic waste* under this lease remain fixed for a period of ten years commencing on the effective date of the lease. At the expiration of each ten-year period, both the lessor and the lessee must conduct a joint technical study to reevaluate the then existing conditions.

According to the lease, the primary purpose of the cubic foot charge on low-level radioactive, chemical, and toxic waste disposed of or buried at the site is to provide funds for satisfactory surveillance in conjunction with the implementation of proper safeguards for the public health and safety upon expiration of the lease term or extension thereof and of final closure. Again, the lease stipulates that the primary purpose for the assessment of the burial rate is to ensure the adequate growth of a perpetual care and maintenance fund.

As was mentioned earlier, the experience of the Beatty site with regard to the development of an adequate postclosure care fund illustrates the necessity of periodically reviewing the fund to ensure that the fees are keeping pace with inflation and changes in the site conditions.

5.3 South Carolina

The Barnwell, South Carolina LLW disposal site was licensed in 1971 by the state of South Carolina. The NRC is currently responsible for the licensing and regulation of special nuclear material. The state of South Carolina and Chem-Nuclear Systems, Inc., the operator of the Barnwell, South Carolina site,

*A hazardous disposal site is colocated and physically adjacent to the radioactive site.

entered into a revised lease in April of 1976 to delineate the responsibilities of the state as lessor, and of Chem-Nuclear as the lessee. The lease agreement for the site requires that Chem-Nuclear undertake all surveillance and maintenance for the protection of the public health and safety so long as it occupies the site. However, if the lessee (Chem-Nuclear) defaults or fails to comply with the terms of its license or for any reason withdraws from the premises, then the lessor would be required to assume surveillance and maintenance obligations and pay the surveillance and maintenance costs. Under the terms of the revised lease, Chem-Nuclear agreed to pay to the lessor, at quarterly intervals, the sum of $.16 for each cubic foot of radioactive waste buried at the site during the preceding quarter. The sum was to be increased every three years on the anniversary date of the lease in accordance with the following formula:

> "In accordance with the Consumer Price Index for all items for the 'south' region as published by the Department of Labor in the Current Labor Statistics-Monthly Labor Review utilizing the March 1976 index as the base."

The escrow fund set up by the parties pursuant to an agreement dated April 21, 1971, for perpetual care of the waste buried at the site continues to be maintained, and any payments made pursuant to that paragraph were added to the fund. Interest earned upon the fund accrues to the fund.

In October 1979, the lease agreement and the license at the site was amended. These new lease conditions stipulated that:

> "The Lessee understands that the storage and burial of radioactive waste require perpetual surveillance and maintenance, and so long as it occupies the Site, the Lessee will undertake all surveillance and maintenance as required by all applicable laws, regulations, and licensing requirements for the protection of the public health and safety. The Lessee further understands that if for any reason at any time it should default, or fail to comply with the terms of its license or for any reason withdrew from the premises, the Lessor would be required to assume surveillance and maintenance obligations and pay the surveillance and maintenance costs. The Lessee, therefore, covenants and agrees to pay to the Lessor, at quarterly intervals, the sum of 55 cents for each cubic foot of radioactive waste buried at the site during the period from September 1, 1979 through April 5, 1980. Payments shall be made at quarterly intervals at the rate of 75 cents per cubic foot of radioactive waste buried at the Site during the period from April 6, 1980 through April 5, 1981, and at the rate of one ($1.00) dollar per cubic foot from April 6, 1981 through April 5, 1982.
>
> ...The parties expressly agree that the escrow fund for perpetual care of the waste buried at the Site established by the parties pursuant to an agreement dated April 21, 1971, and continued pursuant to the lease dated April 6, 1976, shall continue to be maintained and the payments made

pursuant hereto shall be added to such fund. Interest earned upon said fund for perpetual care shall accrue to the fund."

By the end of 1980, Chem-Nuclear had collected $1.7 million for closure and $2.4 million for extended care.

Both the state and NRC licenses were amended to require that the license is to continue in effect, and the responsibility and authority for possession of buried radioactive material continues until a finding that the plan established for preparation of the Barnwell site for transfer to another person (e.g., the state or another operator) has been satisfactorily implemented in a manner to reasonably assure protection of the public health and safety, and the department or NRC takes action to terminate responsibility and authority under this license. All requirements for environmental monitoring, site inspection and maintenance, and site security continue whether wastes are being buried or not.

The lease also requires that the site closure and stabilization of the licensee's facility is to be accomplished in accordance with the U.S. NRC Low-Level Waste Branch Position entitled, "Low-Level Waste Burial Ground Site Closure and Stabilization," Revision 1, dated May 1979.

On May 31, 1980 a preliminary plan for preparation of the site for transfer to another person was submitted for review in compliance with state and NRC license conditions. The plan includes a demonstration that funds are being set aside or that other measures taken are adequate to finance the site closure plan. The license conditions required the plan to include preliminary estimates of costs, environmental impacts, data needs, personnel needs, material and equipment needs, planned documentation and quality assurance, and a detailed plan for trench locations and elevations, expected capacities, planned surface contours, and buffer zones.

In May 1980, the company also submitted a draft trust fund arrangement to the South Carolina state government to handle the collection of closure expenses as part of their preliminary site stabilization and closure plan for the Barnwell site. The terms of the draft, which are currently being negotiated with the state, call for the company to transfer the surcharges collected to a trust fund as it is collected. At the present time, a surcharge of $.78/cubic foot is being collected by Chem-Nuclear to pay for closure costs.

5.4 Kentucky

The Maxey Flats LLW site began operation in 1963 under a license issued by the Commonwealth of Kentucky. The burial ground and adjacent area is owned by Kentucky and was leased to NECO (now U.S. Ecology), the site operator.

In 1976, the Kentucky General Assembly passed an act that imposed an excise tax of $0.10 per pound on all radioactive waste materials delivered in the state for processing, packaging, storage, disposal, or burial. As will be shown later, this change in a surcharge from a cubic foot to a poundage basis drastically reduced the revenues from the waste generators with the result being that the amount in the long-term care funds was inadequate.

In addition to imposing a $0.10 per pound excise tax on all nuclear waste buried in the Commonwealth, the 1976 General Assembly also abolished the Kentucky Science and Technology Commission and transferred responsibility for perpetual care and maintenance of nuclear burial sites to the Executive Department of Finance and Administration. The General Assembly also requested the Legislative Research Commission to appoint a special advisory committee to study the effects of nuclear waste disposal in Kentucky. In its finding and recommendation, the Committee recommended that the 1978 General Assembly amend the nuclear tax to allow for the imposition of a tax based on the relative hazard of the waste material. The Committee made a statement that monies from the nuclear waste tax should be placed in a special escrow account for perpetual care and maintenance rather than in the general fund as was currently the case. The Committee also recommended that a separate perpetual care and maintenance fee should be continued at no less than $0.10 per cubic foot in current 1977 dollars, which was only a slight increase over the current rate of $0.07 per cubic foot. In July 1976 the perpetual care fund contained about $180,000.

In a meeting held July 15, 1976 with NRC staff, Kentucky state officials indicated that funding arrangements for closure had not been adequate. The state government officials estimated that about $100,000 and $150,000 would be needed annually for maintenance to care for the site when it was decommissioned.

After the $.10 per pound surcharge became law on June 19, 1976, the quantity of nuclear waste disposed of at Maxey Flats declined by 95 percent. After the tax was instituted, NECO (now U.S. Ecology) stated that it could not continue to operate the Maxey Flats disposal site under the imposition of the $0.10 per pound tax as currently interpreted by the Department of Revenue.

During the second half of 1976 and 1977, the Maxey Flats site was virtually unused, due to the imposition by the Kentucky legislature of the ten cents per pound excise tax on waste received at the site. Waste generators shipped their materials to other LLW sites who had less expensive long-term care funds. During calendar years 1976 and 1977, 501,609 ft^3 of waste was buried at the site; however, during the period of June 30, 1976 to December 31, 1977, after the tax went into effect, only 29,833 ft^3 of that waste was buried. The site was closed on December 27, 1977 by order of the Kentucky Department of Human Resources until the completion of a water management program, and the completion of further studies to determine the long-term use and safety of the site. In 1978, the Commonwealth of Kentucky under the Department for Human Resources terminated the materials license at the site (License No. 16-NFS-1), issued to NECO, and issued a new license to the Kentucky Department of Natural Resources and Environmental Protection. In May 1978, an arrangement was also signed where Kentucky bought out NECO's remaining lease hold interest in this facility. (The land where the site is located belongs to the state.) Following selection of the site by the state, NECO provided the capital for purchase of the land that was subsequently deeded to the state. The state, in turn, leased the site to NECO for 25 years with an option to renew for an additional 25 years. Currently, the Kentucky Department of Natural Resources and Environmental Protection continues to be the licensee at the Maxey Flats site; however, no wastes are being received at the site at this time. The Maxey Flats long-term care fund contains inadequate funds to pay for postclosure care maintenance and water care activities. A review of the history of the site illustrates the necessity of developing an adequate postclosure care fund that accurately keeps pace with inflation. The experience at Maxey Flat also illustrates how a surcharge being used to collect funds for long-term care can also be used as a punitive tool to reduce capacity at the site. The result will be a situation where the waste generators will go elsewhere, thus reducing the waste received at the site and also the resultant funds for long-term care.

5.5 Washington

In 1965, the receipt, possession, and disposal of source, byproduct, and special nuclear materials at the Hanford, Washington site was licensed by the Atomic Energy Commission. California Nuclear was originally the developer of the site. On December 31, 1966, the state of Washington became an Agreement State and assumed regulatory responsibility for the disposal of all radioactive materials, except special nuclear materials, that continued to be regulated by the AEC. The land on which the Hanford site is located was leased by the federal government to the state of Washington, which in turn, leased it to the site operator. In March 1968, NECO (formerly California Nuclear, the original site developer and now U.S. Ecology) became the licensee.

In 1967, the state of Washington and Nuclear Engineering Company (NECO) amended their Perpetual Care Agreement for the Hanford site, requiring the development of a perpetual care fund. The state determined that the Perpetual Care Agreement should be modified to provide for annual deposits by the state into a perpetual maintenance fund in the same amount as was received by the state from its sublessees (NECO). The fund established by these annual deposits as required by the 1967 Perpetual Care Agreement was to be known as the Perpetual Maintenance Fund, and was to be used exclusively for defraying the costs of perpetual surveillance and maintenance of the site to the extent required by the terms of any applicable laws, regulations, or licensing for the protection of the public health and safety.

Funds in the Perpetual Maintenance Fund are invested by the State Finance Committee in the same manner as other state monies, and any interest accruing as a result of investment would accrue to the Perpetual Maintenance Fund. As of December 1980, approximately $126,000 in escrow funds have been collected for long-term care. Since 1980, these funds have been collected on the basis of a 25¢/cubic foot surcharge. Again, the experience with collecting long-term care funds at this site illustrates the problems that arise when a collection fee is developed that does not accurately reflect changes in inflation and site conditions.

5.6 Kansas

The state of Kansas passed an act in 1979 that authorized establishing fees for monitoring hazardous waste storage sites, paying extraordinary costs and monitoring after the site is shut down, paying the costs of repairing a site and repairing environmental damage caused by a site, or costs of studies, etc., that would be required if early closure is needed (KSA 65-3402, KSA 65-3406, 65-3406a, 65-3406b, 65-3406bc, and 65-3420). The law speaks to all types of hazardous wastes, not just radioactive wastes.

The fees are collected for the purposes of monitoring such sites and facilities both during and after operation. These fees are to be sufficient to reimburse the state for the cost of performing these monitoring responsibilities. In setting fees, the government may exempt those fees that would be payable on recycling processes that recover substantial amounts of either energy or materials from hazardous wastes. The government is to remit any monies collected from such fees to the state treasury.

The funds from the perpetual care trust fund are limited to the following three uses: payment of extraordinary costs and monitoring a site after the responsibility of owner and operating interests has terminated; payment of costs of repairing a site; and costs of repairing environmental damage caused by a site as a result of a postclosure occurrence not anticipated in the plan of operation that poses a substantial hazard to public health and safety or the environment. If an expenditure made under this paragraph would not have been necessary had the person responsible for the operation or long-term care of the site complied with the requirements of the approved plan of operation, a cause of action in favor of the fund shall be accrued to the state of Kansas against such persons. The department shall take such action as is appropriate to enforce this cause of action by recovering any amount so expended. The net proceeds of any such recovery shall be paid into the perpetual care trust fund.

The required fee is not to exceed twenty-five cents (25¢) per cubic foot of hazardous waste or material for each licensee or permittee who (1) operates a hazardous waste storage area under a license issued under the authority of K.S.A. 48-1607 or (2) operates a land disposal site for solid wastes. Each licensee must remit to the state an amount not to exceed twenty-five thousand dollars ($25,000) along with its initial application for a permit, license, or initial renewal as an advance payment of the fees. This advance payment constitutes a credit against any fee that may then be issued.

5.7 New Mexico

The New Mexico radiation protection regulations have a dedicated continued-care fund provision for postclosure care that requires contributions from both uranium mill and radioactive waste disposal licensees.

Uranium mill licensees must contribute $.10 per pound of yellowcake. The requirement of a mill license holder to make deposits to the continued-care fund terminates for each mill after the cumulative continued-care fund deposit for that mill has reached $1 million. The state requirements for a continued-care fund are based on different assumptions than the recently promulgated NRC uranium milling requirements. However, NRC staff discussions with the New Mexico state government officials indicated that the state officials considered that even their own funds were inadequate for ensuring that the uranium milling industry in the state would be responsible for paying for the full costs of postclosure care. A study prepared by Winston Harrington for Resources for the Future also indicated that the state's continued-care fund requirements may not be sufficient for long-term care.

Although at this time there are no radioactive waste disposal operators in the state, the state also has financial requirements for continued care that would have to be met by radioactive waste disposal operators in the state, if such an operation were ever to be conducted in New Mexico. The regulations require that continued-care fund deposits from a radioactive waste disposal license holder are to be made at a rate determined by the Division Director and approved by the Environmental Improvement Board as adequate to cover environmental monitoring and all maintenance and emergency measures, including decommissioning of the site, if applicable. (These deposits are not required of uranium mill licensees.)

Section 74-3-7 of the New Mexico Radiation Protection Act describes the management of this continued-care fund. An earmarked fund called the Radiation Protection Continued-Care Fund is to be created in the state treasury. The collected funds are turned over monthly to the New Mexico Bureau of Taxation and Revenue. Cash balances in the Continued Care Fund are invested by the state treasurer, along with other state funds under his jurisdiction.

Discussions with New Mexico state government officials indicated that funds collected were invested in a variety of accounts. Interest rates earned on the invested funds ranged from 10.5% in December 1979 to 12% earned in May 1980. As of November 18, 1980, the fund contained approximately $3,640,470.

5.8 New York

Nuclear Fuel services, Inc. (NFS) and the New York State Energy Research Development Authority (NYSERDA) are co-licensees at the West Valley site under an NRC provisional facility license, CSF-1. In this arrangement, NFS has operational responsibility for the activities ongoing at the site. NYSERDA's responsibility include site ownership, and the long-term care of the site. Under the terms of the license, NFS has a continuing responsibility for the safety of the site. The license covers conditions for protecting the health and safety of the public and employees associated with the reprocessing of nuclear fuel and storage of the separated wastes.

In 1962, Nuclear Fuel Services, Inc. (NFS), submitted a proposal to the U.S. Atomic Energy Commission to establish a commercial nuclear fuel processing facility at West Valley, New York. In addition to this facility, a low-level waste burial ground was also sited there. In May 1963, after a review of the application, the AEC issued a permit authorizing construction of the NFS plant that was to include a receiving and storage facility to store fuel prior to reprocessing, underground storage tanks for liquid high-level radioactive wastes from the reprocessing operations, and two burial grounds for shallow burial of solid radioactive wastes. (The low-level burial ground was to be regulated by the state and the other burial ground (principally for the use of hulls) was to be regulated by the AEC as part of the facility license.)

NFS, in its proposal, indicated its willingness to maintain and provide storage and maintenance for some finite period of time, thereafter turning over the tanks and wastes to a government agency. NFS also indicated that they were willing to collect and turn over to the state or federal government a charge calculated to provide the estimated full costs for perpetual storage at the point of closure. The funding arrangement contemplated only the eventual transfer of the waste to new tanks, in perpetuity, and did not consider facility decommissioning during the early part of the license term. (In fact, the ultimate reprocessing contract prices permitted NFS to charge under the Base Load Agreement and to its commercial customers included a per kilo charge for perpetual care of the wastes.) The state of New York, through the New York Atomic Research and Development Authority, (NYARDA) provided assurance (as Amendment No. 1 to the application for license) to the federal government that the state would be responsible for the wastes in perpetuity.

However, in order to confirm the costs of perpetual care, the NYARDA requested a study to develop an estimate of the fund that should be set up for perpetual care of radioactive wastes. The results of the study found that a perpetual care fund of $4 million would be sufficient for perpetual care of each filled storage tank, including maintenance, insurance, contingencies, and tank replacement at the end of expected tank life. The October 1962 study also stated that the size of the fund should be adjusted to reflect the actual construction costs of the facility which was not completed until 1966. The fund was to be obtained through annual payments by NFS to NYARDA under the provision of the Waste Storage Agreement. This was one of several agreements negotiated among the parties that provided for postclosure care. Negotiations among NFS, the AEC, and NYARDA led to several contracts and agreements, the main points of which are:

- The amounts paid to NFS by AEC were to include all charges for storage, disposal, and perpetual maintenance of waste at the site.

- At the time the NFS-AEC contract was executed, NFS also entered into several agreements with NYARDA that had the following implications for postclosure care responsibilities:

  - Lease. NFS was granted a lease for the site, with rental payments to be made to the state of New York. NFS would construct, own, and operate the reprocessing facilities. The lease would expire on December 31, 1980, and if the lease was not renewed, New York would then assume ownership of all of the facilities, subject to NFS compliance with other contractual obligations.

> Waste Storage Agreement. Under the terms of this agreement, which was made a part of the lease, NFS was to manage and operate facilities for the storage of high-level nuclear wastes. NFS would be responsible for each tank of high-level liquid waste as it was being filled, and then would turn the tank over to NYARDA for perpetual care. A perpetual care fund was established with the intent of enabling New York to replace the waste tanks every 50 years and to maintain the site. The fund would total $4.0 to $5.1 million by 1980. If NFS wished to recover substances of value from the wastes, NFS could delay transfer of the wastes to NYARDA.

By December 31, 1981, the New York State Energy Research and Development Authority held as a perpetual care fund of $4.5 million for the replacement and maintenance of the high-level waste storage facilities. These monies may be paid to the U.S. Government at a future date for disposal of solidified wastes at a federal repository. In addition, approximately $180,000 was paid NYSERDA by NFS through December 31, 1980 for the low-level waste burial area. These fees, like NFS rental payments have been acounted for as General Authority revenue.

The NFS burial ground was voluntarily closed in 1975 by NFS, due to liquids with low levels of radioactivity seeping out of the soil cap of completed trenches. The state has not allowed operations to resume at the site pending further results of USGS and EPA studies. In April 1976, NFS wrote to the Authority announcing their intention of exercising its right under the Waste Storage Agreement to surrender the responsibility for all wastes at the site to the NYSERDA. Subsequently, New York State informed NFS that the terms and conditions had not been met; and therefore, NFS could not relinquish responsibility for the site. Currently, the lease is in the early stages of legal dispute between the state and NFS; NFS is currently maintaining the site until the final disposition of the land is settled.

5.9 Oregon

Oregon requires an owner or operator to obtain a cash bond in the name of the State to cover closure and postclosure costs. Before the state will issue a permit to an owner or operator, the owner or operator must deed to the state all portions of his disposal site in or upon which hazardous waste will be disposed. (Environmentally Hazardous Wastes, Oregon Solid Waste Control Section 459.600.)

5.10 Texas

The state of Texas has also recently proposed legislation that would require financial guarantees of low-level waste site operators. The legislation, which is expected to be introduced into the Texas legislature in 1981, provides for proposed regulations that require each applicant for a license to demonstrate to a state that he is financially qualified to conduct the licensed activity, including, but not limited to, any required decontamination, decommissioning, reclamation, and disposal. An applicant may be required to provide financial security acceptable to the agency to assure performance of its obligations under this act. (Security here means (1) cash deposits, (2) surety bonds, (3) certificates of deposits, (4) deposits of government securities, (5) irrevocable letters of credit, or (6) other security acceptable to the Radiation Control Agency.)

The draft also established a Radiation and Perpetual Care Fund in the state treasury. The monies from this fund are to be used for any of the following: decommissioning, stabilization, reclamation, maintenance, surveillance, control, storage, or disposal of radioactive material acquired by the agency (the Texas Department of Health). If any licensed activities are found to require maintenance, surveillance, or other care on a continuing or perpetual basis after termination of the licensed activity, the agency may require the licensee to pay annually to the agency for deposit in the Radiation and Perpetual Care Fund, an amount to be determined by the agency.

Each year the agency is to review a licensee's payment to the Radiation and Perpetual Care Fund to determine if the payment schedule is adequate.

5.11 Michigan

Michigan has a model state hazardous waste law, Michigan Act 64, which contains several provisions providing for a state-administered trust fund and, when necessary, assumption of responsibility and liability for the site by the state.

> Sec. 41. (1) An owner or operator of a hazardous waste disposal facility shall file as a part of the application for a licensee to operate, a surety bond or other suitable instrument, or establish a secured trust fund to cover the cost of closing, monitoring, and long-term maintenance of the disposal facility after its capacity is reached or operations have otherwise terminated. The bond, instrument, or fund shall be based upon a reasonable estimate of the cost required to adequately close, monitor, and maintain the site for a period of 15 years or less, as approved by the director...
>
> (2) Following the expiration of the time stipulated in subsection (1), a determination of responsibility of the owner or operator of a disposal facility shall be accomplished by a process established by the rules of the director. If the director determines that the site does not have a foreseeable alternative use, the owner of the site may transfer ownership of the site to the state and the state shall assume the responsibility for the long-term care of the site. After the site is transferred to the state, all claims for injuries occurring after the transfer to persons, property, or the environment brought against the waste generator or the disposal facility owner or operator become the liability of the state.... If a determination is made that the site is suitable for further use, the director shall make the necessary authorization on the restrictive covenant as required in Section 39.

Sec. 42. There is created in the state treasury a disposal facility trust fund. Each owner or operator of a disposal facility shall periodically pay to the department a surcharge fee as determined by rule of the department.... The department shall promulgate rules establishing the method of payment from the disposal facility trust fund for payment of all costs of long-term care of a disposal facility occurring after the responsibility of the owners has been terminated as provided in Section 41.

5.12 Wisconsin

The owner or operator of a hazardous waste facility is responsible for long-term care of his site for either twenty or thirty years after closure (using trust funds, surety bonds, or escrow accounts required by law.) "After that the state assumes responsibility. The State Waste Management Fund is used to pay for costs of long-term care of a site occurring after the owner's or operator's responsibility has ended. The Waste Management Fund is supported by fees collected from facility owners or operators." (1977 Wisconsin Hazardous Waste Management Act (Assembly Bill 1024).)

5.13 New Jersey

"Private firms cannot be relied upon to provide perpetual management and financial responsibility for closed facilities. There are no assurances private firms will remain viable in perpetuity, nor is it likely an insurer will insure against risks forever. Even if one was willing to do so, insurance companies, too, can fail. However, local communities cannot be asked to accept the risk of having a hazardous waste facility operating in their midst unless they are guaranteed protection should potential for harm become actual harm. Since only government has likelihood of perpetual existence, government must at some point take over responsibility for closed facilities.

One way of doing this is to have the state take ownership of the site after closure--or perhaps 20 years after closure, after the operator's RCRA-mandated responsibility has expired. The state would then become responsible for monitoring and for compensating any damaged parties for subsequent pollution. To prevent this from being a form of subsidy to the facility operator, there should be a requirement that the operator leave with the state an escrow fund built up from revenues during the facility's operating life. (Report of the New Jersey Hazardous Waste Advisory Commission to Governor Brendan Byrne, January 1980, p. 47.)

5.14 U.S. Nuclear Regulatory Commission Uranium Milling Regulations

In 1980, the NRC published regulations and an EIS on the Uranium Milling Industry that require financial standards to be met by NRC licensees in the area of uranium mill decommissioning and tailings management. The Commission staff analyzed the financial assurance requirements for decommissioning and long-term care from two different concepts: one, of a short-term or decommissioning surety fund, and two, of long-term care.

Long-term funding refers to the financing of any ongoing care and monitoring that may be required at a mill tailings site after termination of the mill operator's decommissioning responsibilities and license.

The staff concluded that tailings should be disposed of so that no ongoing active care of a disposal site shall be needed after the site is decommissioned. However, the staff also concluded that it would "be prudent to continue monitoring and exercising land use controls at most disposal sites. Such controls, for as long as they could be provided, would constitute an added measure of protection to that provided by physical containment barriers. The purpose of this monitoring activity would be to confirm that the site was not disrupted by natural erosion or by human or animal activities. The nature of the situation of these sites would, therefore, be a passive one. No active maintenance would be required, and costs at individual sites are, therefore, expected to be relatively small, on the order to about $2,500.00 per year in 1978 dollars.

In establishing requirements for funding to cover the costs of long-term monitoring of the mill tailings sites, the staff made a basic assumption with respect to the nature and extent of the effort required for site control. In their development of long-term care costs, the staff assumed that no active care or remedial actions such as irrigation, revegetation, hauling of fill to the site, regrading, seeding, or the like are expected to be needed. There was also no consideration of replacement of fencing that may be left at the site or maintenance of any onsite facilities or equipment. There was also to be no sampling or airborne environmental measurements at the sites. Some ground-water monitoring might be performed by inspectors using portable ground-water sampling equipment. Therefore, the staff concluded that the only cost item would be the time and effort of government inspectors who will visit the sites, their time in travel, making inspections, and preparing for and following up on inspections.

The regulations also require short-term financial assurances of licensees. The purpose of short-term financial sureties is to provide assurances that the mill operator will be around, or that a sufficient sum of the mill operator's money will be around to perform tailings site reclamation. The staff concluded that a number of surety mechanisms were adequate to protect the public against mill operator default prior to performance of reclamation. The alternatives that the staff found acceptable on a generic basis were: surety bonds; cash deposits; certificates of deposit; deposits of government securities; and irrevocable letters of credit. The staff considered that this range of alternatives would allow the mill operator a measure of flexibility in selecting a mechanism that best suits their needs.

5.15 U.S. Environmental Protection Agency Regulations

The Environmental Protection Agency has recently proposed financial requirements for long-term care funds for owners and operators of hazardous waste management facilities. The revised financial regulations for 40 CFR Parts 254 and 265 require assurances that funds will be available when needed for properly closing a hazardous waste facility and for maintaining and monitoring it after closure. (The revised proposal also included a new requirement for liability insurance for facilities in certain states. The coverage is for injuries to people and property that result from the operation of hazardous waste management facilities.)

Owners or operators of treatment, storage, or disposal facilities must establish financial assurance for the closure of their facilities. The owners or operators of disposal facilities must also establish financial assurances for up to 30 years of postclosure care. The owner or operator can establish financial assurances through a trust fund, a letter of credit, a surety bond, or by combinations of these methods. Under the revised regulation, the owner or operator of each hazardous waste facility must prepare a closure plan for the facility. The owner or operator must also prepare a cost estimate for closure of the facility at the point in the facility's operating life when the extent and manner of its operation would result in the greatest closure costs. He must also adjust the estimate of inflation annually and prepare a new estimate when a change in the closure plan affects the cost of closure; inflation must also be taken into account. The applicant can build up the closure trust fund over the expected life of the site, or 20 years, whichever period is shorter. The revised proposed requirements for the trust fund include provisions for adjusting the annual payments in response to inflation, changes in the closure cost estimate, and changes in the value of securities in the trust fund. The EPA staff evaluates the estimates to ensure that the amounts and types of securities in the fund are adequate.

Originally, the general standard required an owner or operator to make a cash deposit equal to the cost estimate for closure, multiplied by the appropriate present value factor, in a closure trust fund as a condition of receiving a permit. The present value factor accounted for growth of the fund over the operating life at a 2 percent per annum real interest rate (interest minus inflation). Based on comments received, EPA decided that a 2 percent real interest rate was too high, so provisions in the revised proposal were based on a zero real interest rate to adequately account for the effects of long-term inflation and trustee fees. Based on long-term data, the EPA said that they felt that over an extended period, the purchasing power of the deposited funds is likely to be static, i.e., the nominal interest realized will be cancelled out by inflation and by trustee fees.

The original proposal did not allow reimbursement of the owner or operator for closure expenses from the trust fund, until closure was completed to the satisfaction of the EPA. This was later amended, since the staff considered this to be too much of a hardship for the operators. Now, if the staff approves, the trust funds can be used to pay for certain costs of decommissioning.

Subpart G of the EPA regulations requires that an operator of a facility prepare a plan for 30 years of postclosure care. The owner and operator must prepare and keep current a cost estimate for 30 years of postclosure care of the facility. At the end of 30 years of postclosure care, any funds remaining in the trust would be returned to the owner or operator.

The proposed regulations stipulate that facilities owned or operated by states or the federal government are exempt from the financial requirements of the EPA.

Another major development in the area of financial management of existing hazardous waste sites was the passage of the "Superfund" bill by Congress in December 1980 (P.L. 96-510). The act sets up a postclosure liability fund of $1.6 billion to clean up abandoned waste sites and hazardous substance releases. The bill also sets up a $200 million fund to take care of present hazardous waste facilities after they are closed. The liability fund assumes all liability for claims made against a site permitted under the Solid Waste Disposal Act for a period of 5 years after the site is shut down by the site owners provided the site meets criteria spelled out in the "Superfund" bill.

The fund is supplemented by a surcharge of $2.13 per dry weight ton of hazardous waste disposed of at facilities. However, the bill also requests the Secretary of the Treasury to conduct a study looking into an optional system of private insurance for postclosure financial responsibility for hazardous waste disposal facilities.

5.16 Department of Interior; Office of Surface Mining

The Office of Surface Mining of the Department of Interior has issued regulations requiring bonding for coal mining operators. The regulations provide that a permitee be required to file a performance bond prior to issuance of a permit for surface coal mining and reclamation operations. The regulations require the applicant to estimate the cost of reclamation, but it is likely that the bond amount set by the regulatory authority may be different, since they have responsibility over determining that the final bond amount is adequate.

Bond amounts must be based on the estimated cost to the regulatory authority and not the operator. By setting the bond in this manner, if the operator forfeits, then the regulatory authority required to do the work will have sufficient funds.

5.17 Conclusions

Based on a review of state and federal financial requirements for closure, postclosure, and long-term care at LLW disposal sites and for other types of hazardous disposal sites, the staff finds that there is a precedent for establishing financial assurances at low-level waste disposal sites in order to protect the public health and safety and the environment and also to ensure that those parties who benefit from the disposal services pay for them.

6. PUBLIC COMMENTS ON PRELIMINARY DRAFT OF 10 CFR 61 CONCERNING FINANCIAL REQUIREMENTS FOR AN LLW SITE

6.1 Workshop Comments on the Draft Regulation

In 1980, the NRC held four workshops in Atlanta (April 21-22), Chicago (July 17-18), Denver (July 14-15), and Boston (November 6-7) that provided state officials, industry representatives, waste generators, the public, and public interest groups with an opportunity to comment on the draft of Part 61. Both the Chicago and Denver workshops had extensive discussions about the financial assurances proposed in the draft LLW regulations.

The workshop discussion on financial requirements ranged from confusion over the NRC's goals in this area to strong recommendations for more stringent regulations. The workshop participants at the meetings concluded that the draft regulations needed more stringent requirements imposed on the licensee with regard to both closure and long-term financial assurances. Workshop participants from state governments, in particular, expressed the view that more stringent, financial guarantees would help to relieve some of the public's resistance towards siting a low-level waste site in their respective jurisdictions.

In their discussions, workshop participants strongly recommended that the long-term care fund should include explicit provisions for unexpected and contingency expenses to protect their constituents from future financial burdens.

- For example, one workshop participant stated that:

  "I think that some errors are going to occur, and that any type of fund that is set up, that is based on the premise that funds need only cover some routine monitoring, and siting is going to be so good at this time because of these new rules that are under development, I think is very naive..."

Staff Comment

The staff agrees with the concept underlying this statement which recognizes that the licensee be responsible for more than just long-term care monitoring at a facility. The proposed regulations require the licensee to be a party to a binding arrangement that ensures that sufficient funds will be available to cover the costs of monitoring and any required maintenance during the institutional control period (emphases added). The site-specific conditions would be evaluated by the staff in order to determine what costs of required maintenance are necessary.

- Another participant echoed this belief that the long-term performance objective of the proposed regulation minimizing the need for long-term care was insufficient to adequately protect taxpayers.

  "I think you know, government makes mistakes, and I think we're going to make mistakes with current siting issues, notwithstanding the fact that the impact statements are written and other documents are produced. I think we're going to find that there are errors in the future, and to decide that there is never going to be a need for continued care, that just a little bit of routine monitoring is going to take care of these things because of the superior decisions to be made now with the new ruling is very naive."

Staff Comment

Provision is made in the long-term care binding arrangement to accommodate more than just monitoring expenses at a site. The proposed regulations require that the binding arrangement provide for any required maintenance during the institutional control period.

- o Members of the workshops also felt that not enough costs were being included in the financial requirements. In particular, Denver workshop participants from western state governments who were already familiar with the uranium mill tailings financial criteria currently being developed by the Commission, expressed scepticism about the adequacy of the draft LLW financial regulations. They felt that the LLW provision for long-term care funds had not gone far enough in protecting taxpayers from possible future expense for long-term care.

Staff Comment

As has been mentioned earlier, the staff lacks authority to require that a license establish funds for perpetual long-term care at a low-level waste site. However, the proposed regulations in Section 61.63 establishes a flexible binding arrangement for long-term care, which will enable the Commission to ensure that financial responsibility is provided for any required maintenance at the site.

- o At the Denver workshop, one participant pointed out that certain naturally occurring phenomena might mandate possible active post-closure maintenance; wind erosion in arid areas and water damage to trenches in humid areas. The workshop included a technical session where one of the industry speakers spoke of the need to include unexpected expenses in the perpetual care and maintenance fund. One industry spokesman stated:

> "Let me offer a suggestion as to how to maybe do that. You've got to back up one step where we've talked about--we said, 'i.e., that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for,' and at this point insert the words 'all unexpected remedial work.'"

Staff Comment

The long-term care funding required in Section 61.63 includes a provision requiring the licensee to provide an assurance for any maintenance which would include remedial work at the site.

- o The spokesman added that,

  "I know in the PC&M (SIC-perpetual care and maintenance) negotiations we've had with all the States that we've operated in, we had incorporated into, that a certain amount of repair work, but we don't expect that the State will ever have to do that; but we said let's be reasonable. Let's put some money in there every year for that, and let's put in a block of dollars to say one time we're going to have a big expense, and we put those dollars in there. Because that's really what we're talking about. If one site has a major problem to solve and the money is not there, they've got to go some place to get it; and the industry should have provided those funds in some way."

Staff Comment

The binding arrangement required in Section 61.63 provides for any required maintenance at the site, and this would have included any necessary repair work for the site.

- o On July 14, 1980, another delegate to the Denver workshop was critical of the draft financial regulations, and suggested that the perpetual care fund needed to incorporate more unexpected costs. The participant stated,

  ".... The fund is based on the idea that the Federal government isn't going to make any mistakes, so there isn't going to be any continued care. We think people are going to make mistakes, and that there may be some need for continued care in the future...." (p. 194 of the July 14, 1980 transcripts)

Staff Comment

See previous comments.

- o Another participant at the Colorado workshop also stressed the importance of including more than just monitoring in the postclosure care fund:

  "...their concept is rather narrow in that they envision just the need for routine monitoring and, I think that based on a premise that they're not going to make mistakes. But anyone who looks at the history of uranium mill tailings, and who looks at the kind of mistakes that have been made in the past ... should easily draw the conclusion, I think, that some errors are going to occur...."

Staff Comment

See previous comment.

- Participants also discussed the wisdom of depositing the long-term care fund into the General Treasury. Some participants favored the use of an earmarked fund in the state or federal government to protect the funds. Another issue raised for extended discussion at the workshops was the possibility of pooling financial assurance funds into a national contingency fund, in order to spread the risk of unexpected cost.

Staff Comment

At this time the Commission lacks the authority to require that a long-term care fund be established.

In addition to the discussions mentioned above, the following specific recommendations were made by the workshops:

6.1.1.1 Chicago Workshop

The group expressed doubt concerning surety arrangements for decommissioning, decontamination, closure, and stabilization. The group approved of the requirement that the surety mechanism be reviewed "from time to time, at the time of the license renewal or more frequently, if necessary." Furthermore, the group believed that financial assurance arrangements should be limited to cash or equivalent. The Nuclear Regulatory Commission should reexamine the appropriateness of a letter or a line of credit as a generally acceptable surety arrangement.

Staff Comment

The staff has concluded that there are a variety of financial assurance mechanisms that offer degrees of security equivalent to cash deposits. A review of the appropriateness of using a letter of credit as a financial assurance has convinced the staff that such a financial guarantee offers adequate financial assurances for recovery in the event of licensee default. Therefore, the staff has decided to retain letters of credit as a financial assurance option for the proposed regulations.

6.1.1.2 Denver Workshop

The workshop participants concluded that the financial assurance requirements should clearly prohibit the option of industry self-insurance. Any financial assurance arrangement should provide for unexpected mistakes and costs. Using the abandoned uranium mill tailings problem as an example, it was pointed out that to assume comparable mistakes will not be made in the future is naive and that financial assurance arrangements to provide for long-term surveillance should include adequate funding to pay for unexpected remedial work. Recognizing the financial difficulties in providing a large enough fund both to take care of unexpected costs and to last over some indefinite period, it was suggested that a portion of the financial assurance funds from all low-level waste facilities be pooled into one national contingency fund. The rationale is that the odds are against all sites experiencing unexpected and costly remedial programs, thereby freeing up some of the funds in their financial arrangements to help pay the costs of those sites that do run into unpredictable contingencies beyond the control of the operator, the state, or the federal government. This would also avoid taxation problems that the facility operators would experience by holding this money themselves.

In addition to pooling the financial assurance funds of the facility operators, it was also suggested as an alternative, that a federal tax be levied, either on the front-end user of the product whose production resulted in LLW (e.g., electricity production) or on the back-end waste disposer. This tax would be exclusively earmarked for deposit in the LLW national contingency fund, recognizing that LLW disposal and perpetual care is a national responsibility.

There was a general consensus that a standard, specified method of calculating costs was inappropriate, because such costs would be site-specific. A list of criteria needed to be considered in calculating costs could be provided, but how these criteria would be calculated in determining costs would depend on the specific site.

Staff Comment

Several issues were raised in the Denver workshop conclusions, namely.

- Regulations should prohibit self-insurance.

  The staff agrees and Section 81.51(g) states that "self-insurance, or any arrangement which essentially constitutes pledging the assets of the licensee will not satisfy the surety requirement for private sector applicants since this provides no additional assurance other than that which already exists through license requirements."

- Long-term financial assurance arrangements should include adequate funding to pay for unexpected remedial work.

  The staff agrees and the long-term care financial assurance mechanism proposed in 61.63 states that responsibility for all necessary maintenance costs are to be provided for.

- Calls for a national contingency fund.

  The Commission currently lacks the authority to establish such a shared pool, and hence, the staff cannot propose such a mechanism in the regulations.

- Recommends levying a federal tax on producers of LLW in order to have all users pay for LLW disposal and perpetual care.

  The staff agrees with the equity decision that those parties benefiting from an LLW site should be responsible for the costs of such an LLW site. However, the Commission lacks the authority to require that a surcharge be levied on waste users. Therefore, the staff has not been able to incorporate such a cost-recovery mechanism into the proposed regulations. However, certain Agreement States with such taxing authority who have an LLW site located within their jurisdiction may wish to consider levying such a surcharge for closure and/or long-term care costs.

- A standard, specified method of calculating costs is inappropriate because such costs are site specific.

  The staff agrees, and has tailored the proposed regulations so that the financial provisions for both the short- and long-term case provisions will be on a site-specific basis.

6.1.1.3 Altanta Workshop

Generally, the financial assurance section is adequate. However, a specific problem may exist with open-ended financial assurance requirements. Calculating costs is a site-specific problem. The goal of Part 61.28, setting up a fund for postoperational costs, is difficult but very necessary.

6.1.1.4 Boston Workshop

The group emphasized the need for setting adequately high disposal fees so that the perpetual care fund would be large enough to cover the costs of anticipated and unanticipated postoperational needs. The group noted that several states are now saddled with large postoperational expenses that cannot be covered by the low disposal fees charged during its operation.

The group also briefly discussed financing. In view of the present high rate of inflation, the group expressed concern that the value of the perpetual care fund would decrease over time. One suggestion made by a participant was that every ten or twenty years before license termination, the government should recalculate the value of the fund so that if its value had decreased over time, corrective action could be taken.

Staff Comment

Currently, the Commission lacks the authority to establish a fund for long-term care of an LLW site, so they cannot set standards for how such a fund would be adjusted to account for inflation, charges in site conditions, etc. However, for those Agreement States wishing to set up a long-term fund, the staff agrees with the Boston recommendations that if such a fund were to be established by a regulatory agency, that there should be consideration of annual inflation adjustments.

6.2 Written Comments on the Preliminary Draft Regulation

After the Commission circulated their preliminary draft (November 1979) of the LLW regulation, they received a variety of written comments concerning the financial requirements found in 10 CFR Part 61.

As of July 30, 1980, the following comments had been received specifically addressing the financial requirement of the proposed regulations.

1. Walt Rodgers, Nuclear Safety Associates, "Some of the proposed requirements for funding could well lead to prohibitively high front-end costs. The basis for the assumption of 1% real interest should be documented."

Staff Comment

The staff has removed the perpetual care fund provision for long-term care from the proposed regulations, and therefore, there is no reference to a 1% real interest rate.

2. Chem-Nuclear Systems, Inc. examined the preliminary regulation and remarked, "The requirement of subsection 10 CFR Part 61.28(a) lacks specificity and therefore will be difficult, if not impossible, to review and administer." Chem-Nuclear also suggested that the Commission revise the requlations to require specific performance criteria, or that the requirements be eliminated altogether. Chem-Nuclear also felt that the requirements of also lack specificity in the language.

Staff Comments

The staff agrees that more specificity is needed in the language, and the regulations have been amended to include more detailed requirements.

3. The California Energy Resources Conservation and Development Commission generally approved of the draft regulation on the long-term care fund. They stated that requiring the licensee to provide "financial surety, covering all costs to safely terminate the facility and to monitor the facility after shutdown is appropriate and necessary. They also said, "the authors of the regulation were astute to require that the licensee estimate termination costs under the assumption that operations would be performed by an independent contractor (61.28(b))." The California Commission suggested that the wording of the section be changed to make its intent somewhat clearer.

Staff Comments

The staff agrees with this comment and has amended the proposed language to make the intent more clear.

7. BACKGROUND REFERENCE MATERIALS

The following section presents summaries of studies and reports dealing with the financial aspects of closure and long-term care at hazardous facilities. The materials provided were used by the staff in the development of the financial requirements.

1. In December of 1979, the NRC published the draft of a report entitled "ASSURING THE AVAILABILITY OF FUNDS FOR DECOMMISSIONING NUCLEAR FACILITIES" (NUREG-0584, Revision 1).

   The report stated that the NRC had undertaken a comprehensive reevaluation of its policy regarding the decommissioning of nuclear facilities. Until regulations on uranium mills were recently proposed, NRC regulations had been generally silent with regard to decommissioning nonreactor facilities, although decommissioning of these facilities had been generally addressed in their licenses.

   The NRC staff developed five criteria to evaluate the relative effectiveness of the alternative financial assurance mechanisms being considered: The first criterion used is the actual degree of assurance provided by the alternative. The second is the cost of providing the assurance, in both direct dollar costs and indirect administrative costs. The third criterion is the equity of the alternative. The fourth is the degree to which the alternative is responsive to changes in inflation and interest rates, to changes in estimated or actual operating life, and to changes in technology that decrease or increase ultimate decommissioning costs. Fifth is the ability of the alternative to handle effectively differing ownership and jurisdictional arrangements existing in the particular industry. The NRC staff found that there were six basic alternatives for assuring the availability of funds for decommissioning costs; prepayment of decommissioning costs; a funded reserve over the estimated life of the plant, an unfunded reserve, or funding at decommissioning; surety bonds, decommissioning insurance, and funding from general tax revenues. (Note: as used here, surety bonds are defined to include bank letters and lines of credit.)

   The report also examined the Federal Income Tax considerations of the various funding arrangements. Under Internal Revenue Service regulations, decommissioning expenses for other nuclear facilities and licensees would not be deductible from income until actually incurred. A blind trust could be established with the principle from such a trust invested in tax-free securities, such that both contributions to principal and interest would not be subject to federal tax. The report emphasized that in this regard, nonreactor licensees have the same range of accounting options as do utilities. Funded and unfunded reserves can be structured so as to take advantage of accelerated depreciation, through normalization or flow-through accounting methods, by net-after-tax funding, or by any of the other methods that are used by utilities.

The report concluded that the deposit at the start-up method for the collection of postclosure costs, provided the greatest assurance that funds would be available; and that deposits of postclosure funds at the period of decommissioning provided the least assurance that sufficient closure funds are available. In their conclusions and recommendations, the study found that the most secure method for development of a postclosure care fund appeared to be the deposit at start-up method. The development of a sinking fund or an escrow account was also found to be acceptable in these cases with little likelihood of premature shutdown. The report also noted that, unlike reactors, smaller facilities have the option of surety bonding and concluded that it may be acceptable if the bond is not able to be terminated by the surety company.

2. On November 1978, the Commission released a SECY paper (SECY 78-613) that examined whether the Commission should require financial regulations for its low-level waste management program. The request for a financial regulation for perpetual care had been made by the Natural Resources Defense Council in a petition for rulemaking for low-level waste management. One of the alternative methods to provide long-term funding that was recommended by the petitioner was the establishment of a regulation requiring a special fund based upon a cubic-foot charge. However, as the Commission's Notice of Denial of Petition for Rulemaking noted, legal problems existed that prevented the Commission from establishing a long-term care fund through fees based on the volume of materials. Although fees for use of property can be established between the landlord and the tenant as is currently the case, to order a fee-per-unit volume of waste by Commission regulation and to establish an earmarked fund would require Congressional authorization. A federally mandated fee-per-unit volume of waste that is not a product of the landlord/tenant contract would in essence be a tax-requiring legislative enactment. (See Federal Power Commission vs. New England Power Co., 415 U.S. 345 [1974]; National Cable Television Association, Inc., vs. United States 415 U.S. 336 [1974].) The establishement of a special fund based upon such a tax would also require special legislation.

3. In December 1979, the NRC released "Decost-Computer Routine for Decommissioning Cost and Funding Analysis" (NUREG-0514). The study developed a computer routine for the analysis of decommissioning costs and funding mechanisms. The DECOST model calculates the costs of and evaluates the payments for decommissioning nuclear facilities, including postclosure costs under varying economic and planning conditions. As used in this study, decontamination and decommissioning are defined as the "removal of the radioactively contaminated and activated materials from the site to appropriate disposal sites or the containment of the materials away from the general public." The DECOST study used seven possible methods for funding the decommissioning of the facilities: (1) use of a constant-fee sinking fund; (2) use of an escalating-fee sinking fund; (3) use of a deposit

to cover the costs at the expected end of life; (4) use of a deposit to cover the decommissioning costs at the time of the deposit; (5) use of the previous method, but with net earnings returned to the utility; (6) use of straight-line, negative salvage value depreciation of the facility; and (7) use of adjusted straight-line negative salvage value depreciation of the facility.

The DECOST program package can be run to allow planning to reduce the costs and financial risks of all types of nuclear facilities, and to allow wide ranging study of the various options available when planning for decommissioning of nuclear facilities.

4. In 1977, Science Applications, Inc., published a report entitled "The Financial Alternatives for Stabilization, Reclamation, and Long-Term Monitoring, and Maintenance of Uranium Mill Tailings Piles." Alternative financing approaches were evaluated for assuring short-term tailings stabilization and reclamation, and long-term monitoring and maintenance. Short-term financing assurances considered included surety bonds, cash deposits, certificate of deposits, deposits of securities, secured interests in an operator's assets, letters of credit, and self-insurance. The most favorable short-term financing alternatives were determined by a rating system that evaluated administrative time; operator expense; loss of productive use of corporate assets; flexibility of surety value; ease of collection in case of default; and problems encountered in asset valuation.

   For long-term financing alternatives, three methods were considered: uranium product taxation, surety bonds and other performance guarantees, and mill operator generated funds. Only specific approaches within the last categories were considered acceptable. These alternatives were: an earmarked annuity managed by the regulatory body; purchased investment securities managed by the operator during the active milling period; and a lump sum final payment secured by surety bonding.

5. The Western Interstate Nuclear Board Committee on Mining and Milling of Nuclear Fuels also issued policy recommendations related to the financing of stabilization and perpetual surveillance and maintenance of uranium mill tailings.

   The objective of the April 1977 study was to determine appropriate methods of financial responsibility for stabilization and perpetual maintenance of uranium mill tailings as a means of reducing potential radiation exposure. Long-term financial responsibility was needed in the event of noncompliance or insolvency by a licensed uranium mill operator, and the subsequent assumption of responsibilities for remedial actions and monitoring by government agencies.

   Among their recommendations, the Committee found that long-term financial requirements for maintenance and surveillance of the stabilized pile by the responsible agency should be assured through the accumulation of an annuity by a separate tax or fee per ton of ore processed. The Committee also recommended that provision be made in licensing agreements for transferring ownership of final disposal sites, with all mineral rights, to the government agency responsible for maintaining the stabilized tailings pile. A price adjustment index was also recommended for adjusting the taxes, fees, or bonds, in order to maintain the purchasing power parity of the financial requirements identified in the above recommendations.

6. During June 1974, the Task Force on "Bonding and Perpetual Care of Licensing Nuclear Activities" was established by the Executive Committee of the National Conference of Radiation Control Program Directors in joint sponsorship with the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). The specific charge of the Task Force was to examine in detail the requirements for establishing bonding and perpetual care programs for all types of licensed nuclear activities, and to report the findings of the task force as guidelines to assist states in program development.

   The study examined the status of bonding programs related to licensed nuclear activities (excluding waste burial licensees) and found that only one state, New York, had instituted such a program. During 1975, both North Carolina and Arkansas assessed bonding legislation. The reports examined four major areas: (1) the determination of the licensed activities that may require consideration for bonding and or perpetual care; (2) to identify the legislative authority necessary to establish bonding and perpetual care programs; (3) to develop monetary ranges of performance bonds and perpetual care trust funds; and (4) to identify specific administrative areas to be considered by the state in developing, implementing, and maintaining bonding and perpetual care programs.

   As a prerequisite for certain licensees to possess radioactive materials, the Task Force concluded that a financial responsibility review system should be instituted at both the state and federal level. They also found that other alternatives to bonds and perpetual care trust funds have been considered and were, at that time, generally not viable.

   The Task Force report included the recommendation of the 1974 National Conference on Radiation Control, which was that a perpetual care trust fund be legally established that would draw interest adequate to pay the costs of monitoring and maintaining the decommissioned site. The perpetual care trust funds would be identified and their use limited to the monitoring, maintenance, and other perpetual care at the radioactive waste burial site. Items to be considered in determining the perpetual care trust funds are:

   - surveillance, including salaries, travel expenses, instrument maintenance, overhead, and well drilling.

- maintenance of site, including labor, salaries, overhead, special equipment (evaporators, etc.), fence repair, and erosion control.

- contingency fund, including protective actions to prevent unacceptable release of waste material from the site, including land acquisition and blocking procedures.

Another recommendation was that performance bonds should be posted by the burial site operator payable to the state agency having the responsibility for closing and maintaining the site in the event of default or other inability of the operator to meet the requirements of the regulatory authority or contract. The report suggested that the performance bond should be adequate to cover the following costs: (a) the decommissioning of the site so as to require minimum maintenance; (b) the payment of funds due the perpetual care trust fund at the time of default; (c) the maintenance and monitoring of the site for at least one year to permit possible site reactivation, if so desired.

7. In 1976, the South Carolina State Department of Health and Environmental Control commissioned a study by Clemson University to examine the state's funding arrangements for meeting the state's obligations for maintenance, surveillance, and contingency costs associated with the Barnwell site. The state required Chem-Nuclear Systems, Inc., as a condition of their license, to pay $.08 per cubic foot of radioactive material buried at the Barnwell site. The fee was passed directly on to Chem-Nuclear System's clients. No study was done to arrive at the decision to set the charge at $.08 per cubic foot. The researchers were asked by the state to determine what should be the charge per cubic foot of radioactive materials to assure that the sinking fund would, in perpetuity, adequately finance all routine and contingency costs associated with managing the Barnwell site, so as to pose no threat to man or his environment, and also to determine what funding arrangements are needed to protect the state of South Carolina in the event the licensee ceases operations before the expected decommissioning date. The four specified objectives of the study were: (1) to estimate the annual costs of routine maintenance and surveillance at the Barnwell site, including salary and labor costs, travel expense, instrument maintenance and depreciation, sampling and laboratory costs, and costs of erosion control practices; (2) to establish procedures for estimating contingency costs associated with emergency conditions that may threaten the health and safety of the surrounding population; (3) to estimate the per-cubic-foot contribution to the sinking fund needed to establish a fund sufficient to meet all routine and continuous costs in perpetuity; and (4) to examine alternatives for protecting the taxpayers of the state from being required to assume custodial costs for the Barnwell site, as a result of failure of the licensee to fulfill its obligations.

In their conclusions and recommendations, the authors of the Clemson study found that the costs of meeting the state's possible future responsibilities toward the Barnwell site should be borne out of interest earned on the sinking fund, and that the principal should be protected intact. They found that the charge of $.08 per cubic foot was inadequate to create a sinking fund of sufficient size to yield returns that would cover even routine responsibilities of the state relative to the site. With the existing rate, the study found that the state would be required to fund about one-half of the cost of meeting their routine obligations toward the Barnwell site out of general tax revenues. Major unexpected problems would create even more of a burden to the state's general tax revenues.

The study used the long-run real return on U.S. Government bonds as the basis for estimating an appropriate rate of interest for use in this analysis. This was done by estimating the long-run real return by examining yields on high-quality municipal bonds from 1900 to 1912 and on U.S. Government bonds from 1913-1973. The study then corrected these yields for increases in the wholesale price index. In the most recent period from 1969, the mean real rate of return was found to be 1.64 percent per annum. The study used two percent as the real rate of return in their calculations.

Based on their analysis, the study recommended that a declining-term performance bond represented the best approach for protecting the state against a default by the licensee.

The study offered three final recommendations: (1) the fee levied on each cubic foot of radiological waste material buried at the Barnwell site should be increased from $.08 to $.14 as soon as possible; (2) the licensee should be required to post a declining-term performance bond to protect the state against default by the licensee, with that bond equal to $1.6 million in 1975, and declining by no more than $90,000 in any year; and (3) that the licensee be declared in default, and the performance bond forfeited, should it cease operations at the Barnwell site for any reason prior to June 30, 1995.

8. The Kentucky Legislative Research Commission also released a study by the Research Triangle Institute that did a financial analysis of perpetual care and maintenance for the Maxey Flats disposal site. The study estimated those costs (i.e., site maintenance, surveillance and monitoring, and water treatment) associated with a perpetual care and maintenance site for a variety of different scenarios. The study found that contributions to a perpetual care and maintenance fund sufficient to raise the fund to a level necessary to care for the Maxey Flats site in perpetuity, must be between $.010 and $.020 per cubic foot and be indexed to the rate of cost inflation. The study found that the initial contribution rate was dependent upon assumptions about annual costs in 1977 dollars, the rate of inflation, and the disposition of funds from a tax based on radiotoxicity of the buried waste that was being proposed by NECO, the site operator.

9. In January 1978, Winston Harrington of Resources for the Future, published a report entitled "Continued Care of Uranium Mill Sites: Some Economic Considerations." The report analyzed the financial adequacy of the New Mexico State Environmental Protection Agency's perpetual care funds for uranium mills. The purpose of the fund was to provide for the maintenance in perpetuity of the mill sites after decommissioning. The state was authorized to require each mill to contribute up to 10 cents per pound of yellowcake (U_3O_8), until a total of $1,000,000 was deposited by that mill. The author argued that even this maximum amount of $1,000,000 proposed by the state was inadequate to generate an income stream that would support an adequate maintenance program at the sites. The author assumed that the continued care fund would have to be sufficient to meet the following expenses at the mill site:

   o Fencing is assumed to be around the tailings pile, which will have to be replaced when it wears out. Repairs will also have to be done.

   o Monitoring of the site is necessary on at least an annual basis. Repairs will have to be made if the structural integrity of the pile has been compromised by erosion or animals.

   o Ground-water quality must be monitored.

   o If case of a natural disaster, repairs may be necessary.

   o Unanticipated problems must be considered. Revegetation is not included.

   The author developed two criteria that he assumed a perpetual care fund must satisfy:

   o Based on currently available information on costs and interest and inflation rates, the fund should generate an income stream sufficient to meet all maintenance costs, (i.e., fencing, monitoring and repair, emergencies, and unanticipated problems); and

   o The terms of the continued care contribution should be readily alterable as new information becomes available. Thus, the perpetual care contribution from a mill operating ten years from now should reflect ten additional years' data for inflation and maintenance costs.

10. In September of 1980, the Texas Advisory Committee on Nuclear Energy on Low-level Nuclear Waste Disposal prepared a report on low-level waste management that dealt with the economic considerations of decommissioning and postclosure care for a low-level waste site. The report recommended that the disposal fees for an LLW site should

include an assessment to accumulate an extended-care fund. The Department of Health would be responsible for annually reviewing the cubic foot assessment for the extended-care fund. The funds collected for extended care are to be deposited with and managed by the Department of Health with the purpose of assuring proper decommissioning when the site is closed and assuring long-term maintenance and surveillance of the site. The report indicates that provisions for the extended-care fund ultimately should be incorporated into a constitutional amendment to assure long-term protection of the fund.

11. The NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds (NUREG-0217) also examined the long-term care of disposal sites.

    Officials from the states indicated that under present leases, low-level waste burial ground operators could abandon sites at any time without a continuing financial obligation for long-term care and maintenance.

    In all states except Illinois where disposal fees are paid into the general state funds, a specific fund has been established for perpetual care of sites. The money is paid to the state by the operator and is based on per-cubic foot burial charges, which range from 5¢/ft^3 to 16¢/ft^3.

    With the possible exception of the South Carolina site, neither the state members nor the Task Force members believed that funds were being accrued at a rate sufficient to adequately care for the sites.

    The report also mentioned that the Task Force Report on Radiation Control Program Directors recommended that annual interest from perpetual care trust funds for low-level waste sites should total between $50,000 and $250,000 depending on ground characteristics. Such an amount would be sufficient to pay for the annual long-term costs of monitoring, minor maintenance, and surveillance.

    Initially, the funds were established to provide money from interest for perpetual care of the sites. They were not considered as resources for corrective action, since major problems in site operations were not expected.

    However, with recent operational problems at several sites, the report noted that site operators have reevaluated use of the funds and found that it was evident that present funds were insufficient for major corrective actions.

    Furthermore, such use of the funds would deplete the principal, leaving little money for long-term care. All states indicated that they would need federal financial and technical assistance if major deficiencies in site performance are found at the burial sites.

BIBLIOGRAPHY

American Nuclear Insurers, Reports, Farmington, Connecticut, 1977-1980.

Burt, et al., Draft Final Report, An Analysis of Methods for Ensuring Continuity of Operations for Hazardous Waste Disposal Sites, International Research and Technology Corporation (IRT-21600), April 1980.

Chem-Nuclear Systems, Inc., Preliminary Site Stabilization and Closure Plan for the Barnwell Low-Level Radioactive Waste Disposal Facility, May 1980.

Clemson University, South Carolina Agricultural Experiment Station, Department of Economics and Rural Sociology, Agricultural Economics and Rural Sociology Report - Economic Analysis of Funding Arrangements for Maintenance, Surveillance, and Contingency Costs Associated with Burial of Low-Level Radioactive Waste in South Carolina, December 1974.

Conservation Foundation, Dialogue Group on Low-Level Radioactive Waste Management, Toward A National Policy for Managing Low-Level Radioactive Waste: Key Issues and Recommendations, A Report to the U.S. Department of Energy by the Conservation Foundation Dialogue Group on Low-Level Radioactive Waste Management, Washington, D.C., June 1981.

Cunningham, Richard E., Testimony before the Environment and the Atmosphere Subcommittee of the House Committee on Science and Technology Regarding Nuclear Fuel Services, Inc., West Valley, New York, June 15, 1977.

Government Institutes, Inc., RCRA Financial Responsibility and Closure/Postclosure Plans Seminar, June 8, 1981, Washington, D.C.

Harrington, Winston, Continued Care of Uranium Mill Sites: Some Economic Considerations, Resources for the Future, Washington, D.C., January 1978.

Kentucky Legislature Research Commission, Report of the Special Advisory Committee on Nuclear Waste Disposal, Research Report No. 42, Frankfurt, Kentucky, 1977.

Lipschutz, Ronnie D., Radioactive Waste: Politics, Technology, and Risk, 1980.

League of Women Voters Education Fund, A Nuclear Waste Primer, Washington, D.C., 1980.

Lehtinen, Silvennoinen, and Viva, "Allowing for Uncertainties in the Expected Waste Management Costs," Radioactive Waste Management, Vol. 1, No. 1, 1980.

National Governor's Association, Draft Report - Task Force on Low-Level Radioactive Waste Disposal, August 1980.

Science Applications, Inc., Financial Alternatives for Stabilization, Reclamation and Long-Term Monitoring and Maintenance of Uranium Mill Tailings Piles, prepared for Argonne National Laboratories.

Science Applications, Inc., Update of Financial Alternatives for Stabilization and Reclamation of Uranium Mill Tailings Piles, prepared for Argonne National Laboratories.

Schwent, Vincent, Costs and Financing of Reactor Decommissioning: Some Considerations, California Energy Commission, September 1978.

Smith, Clifford V., Testimony Before the Environment, Energy, and Natural Resources, Subcommittee of the House Committee on Government Operations, Regarding Nuclear Fuel Services, Inc., West Valley, New York, March 8, 1977.

Smith, Gerald W., Engineering Economy: Analysis of Capital Expenditures, 3rd Ed., 1979.

Texas Advisory Committee on Nuclear Energy, Nuclear Energy in Texas: Major Issues and Policy Recommendations, Austin, Texas, December 1979.

U.S. Government, Comptroller General, Cleaning up the Remains of Nuclear Facilities - A Multibillion Dollar Program, Report to the Congress by the Comptroller General of the U.S., June 16, 1977.

U.S. Government, Comptroller General, Issues Relating to the Closing of the Nuclear Fuel Services, Incorporated, Reprocessing Plant at West Valley, New York, March 8, 1977.

U.S. Government, Congress, House Committee on Government Operations, Hearings on Low-Level Radioactive Waste Disposal, 94th Congress, Second Session, February 23, March 12, April 6, 1976.

U.S. Government, Congress, House Committee on Interstate and Foreign Commerce, Hearing on Long-Term Risks of Hazardous Waste Sites: Post-Closure Liability, 96th Congress, Second Session, July 25, 1980, Washington, D.C.

U.S. Government, DOE, Low-Level Radioactive Waste Policy Act Report, Response to Public Law 96-573, (DOE/NE-0015), 1981.

U.S. Government, DOE, Technology for Commercial Radioactive Waste Management, (DOE/ET - 0028), May 1979.

U.S. Government, DOE, Understanding Low-Level Radioactive Waste, U.S. DOE, Idaho Operations Office (LLWMP-2), November 1980.

U.S. Government, DOE, Western New York Nuclear Service Center Study Companion Report, TID-28905-2.

U.S. Government, DOI, Office of Surface Mining Reclamation and Enforcement, Surface Coal Mining and Reclamation Operations, March 13, 1979.

U.S. Government, EPA, Proposed Hazardous Waste and Consolidated Permit Regulations, May 19, 1980.

U.S. Government, ERDA, NRC, NSF, CEQ, and EPA. Proceedings of the Conference on Public Policy Issues in Nuclear Waste Management, Chicago, 1976.

U.S. Government, EPA, Hazardous Waste Management System: Addition of General Requirements for Treatment, Storage and Disposal Facilities, 40 CFR Part 265; Amendment of Interim Status Standards Respecting Closure and Post-Closure Care and Financial Responsibility (40 CFR Part 265), Part 11, Federal Register, January 12, 1981.

U.S. Government, EPA, Federal Register Hazardous Waste Facility Siting: A Critical Problem, July 1980.

U.S. Government, Federal Maritime Commission, 46 CFR, Part 542, 543, 544.

U.S. Government, Interagency Review Group on Nuclear Waste Management, Report to the President, Washington, D.C., March 1979.

U.S. Government, OMB, Evaluation, Review and Coordination of Federal and Federally Assisted Programs and Projects, FR, Vol. 41, No. 8, January 13, 1976.

U.S. Government, NRC, Docket No. PRM-50-22, Response to and Partial Denial of Petition for Rulemaking Filed by the Public Interest Research Group, et al., Federal Register, Vol. 44, No. 122, Friday, June 22, 1979.

U.S. Government, NRC, Office of Standards Development, Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities, NUREG-0436, Rev. 1, Supp. 1, 1980.

U.S. Government, NRC, Conference Proceedings for State Workshops for Review of the NRC's Decommissioning Policy, NUREG/CP-0003, 1978.

U.S. Government, NRC, and Battelle Pacific NW Laboratories, Fuel Cycle Cost Projections, NUREG/CR-1041, December 1979.

U.S. Government, NRC, and Battelle Pacific NW Laboratories, Decommissioning of Nuclear Facilities - An Annotated Bibliography, NUREG/CR-0131, 1978.

U.S. Government, NRC, Office of Nuclear Material Safety and Safeguards, DECOST-Computer Routine for Decommissioning Cost and Funding Analysis, 1978.

U.S. Government, NRC, Office of Nuclear Reactor Regulation, Assuring the Availability of Funds for Decommissioning Nuclear Facilities, NUREG-0584, Rev. 2, 1980.

U.S. Government, NRC, and Battelle Pacific NW Laboratories, Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570, June 1980.

U.S. Government, NRC, Office of Standards Development, Analyses of Comments on 10 CFR Part 72, NUREG-0587, 1980.

U.S. Government, NRC, Office of State Programs, Final Task Force Report on the Agreement States Program, NUREG-0388, 1977.

U.S. Government, NRC, Office of Standards Development, Thoughts on Regulation Changes for Decommissioning, NUREG-0590, Rev. 2, 1980.

U.S. Government, NRC, Response to Natural Resources Defense Council, Inc. Petition for Rulemaking (PRM-20-7), SECY-78-613, November 24, 1978.

U.S. Government, NRC, Submission of Low-Level Waste Implementation Plan, SECY-77-489, September 12, 1977.

U.S. Government, NRC, Pacific NW Laboratory and Battelle Human Affairs Research Centers, Decommissioning Commercial Nuclear Facilities: A Review and Analysis of Current Regulations, NUREG/CR-0671.

U.S. Government, NRC, and National Governor's Association, Improving Regulatory Effectiveness in Federal/State Siting Actions - State Perspectives on Energy Facility Siting, (NUREG-0198), March 1978.

U.S. Government, NRC, Proposed Rule, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions and Related Conforming Amendments, FR, Vol. 45, No. 43, March 3, 1980.

U.S. Government, NRC, Regulation of Federal Radioactive Waste Activities, Washington, D.C., NUREG-0527, September 1979.

U.S. Government, NRC, Office of Standards Development, Draft Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities, NUREG-0586, January 1981.

U.S. Government, NRC, Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds, NUREG-0217, 1977.

U.S. Government, NRC, Report to Congress on Means for Improving State Participation in the Siting, Licensing, and Development of Federal Nuclear Waste Facilities, NUREG-0539, March 1979.

U.S. Government, State Planning Council on Radioactive Waste Management, Docket Book, Fourth Meeting, Arlington, Virginia, September 8-9, 1980.

Western Interstate Nuclear Board, Policy Recommendation on Financing Stabilization, Perpetual Surveillance and Maintenance of Uranium Mill Tailings, April 1977.

New York State Energy Research and Development Authority, Report of the New York State Energy Research and Development Authority with Respect to Federal Acquisition of the West Valley Facility, 1977.

U.S. Comptroller General, Further Analysis of Issues at Western New York Nuclear Service Center, EMD-81-5, October 23, 1980.

U.S. Department of Energy, Western New York Nuclear Service Center Study, Companion Report, TID-28905-2.

Appendix L

(Reserved for final EIS)

Appendix M

POTENTIAL LONG-TERM IMPACTS OTHER THAN GROUND WATER MIGRATION AND INADVERTENT INTRUSION

This appendix addresses potential long-term radiological impacts associated with near-surface disposal of radioactive waste other than those directly associated with ground-water migration and potential inadvertent human intrusion. These latter impacts are extensively addressed in Chapters 4 and 5 of this environmental impact statement. These impacts may be divided into three areas:

- o Gaseous releases from decomposing wastes.
- o Plant and animal intrusion.
- o Erosion.

Potential ways to mitigate such impacts are also addressed.

1. GASEOUS RELEASES FROM DECOMPOSING WASTES

Much of the waste currently being disposed in shallow land burial facilities consists of organic material such as wood, paper, or animal carcasses. As such buried organic material decomposes over time, gaseous decomposition products such as CO_2 or CH_4 (methane) are formed which can be transported upward, through the trench caps, and into the atmosphere. Such decomposition gases can contain tritium (H-3, or T), C-14, or other radioisotopes contained in the disposed waste.

As stated by EPA in connection with decomposition gases generated at sanitary landfills (Ref. 1):

> A major product of landfill waste decomposition processes is a gaseous mixture consisting largely of methane (55 percent) and carbon dioxide (45 percent), with trace amounts of elemental nitrogen, hydrogen and oxygen, and varying trace constituents such as ammonia, carbon monoxide, ethylene and water vapor. The extent of gas production depends primarily on landfill age, percent and type of waste organic materials, cover material permeability and thickness, landfill temperature variation, waste density and moisture content. Once generated, methane can migrate radially by diffusion and convective flow processes through the gas permeable waste and the adjacent and overlying soil. Under certain conditions, the methane can collect in explosive concentrations (5 to 15 percent in the presence of air) in conduits or buildings adjacent to the landfill. The presence of methane can also result in damage to a variety of plant species due to reduced oxygen concentrations in the plant root zone. Carbon dioxide will dissolve in ground water forming carbonic acid, therefore mineralizing and contaminating it. A common methodology utilized to predict the potential extent of methane migration is to assume that ten feet of horizontal methane migration may occur for each foot of landfill depth. The resulting value is only a very general estimate, since site specific subsurface conditions such as an impermeable cover and porous substrata can result in methane migration on the order of hundreds of feet.

The presence of tritium and carbon-14 tagged decomposition products at shallow land burial facilities was first observed by Matuszek, et al. (Refs. 2, 3). Samples of gases collected from trench sumps at the Maxey Flats, Kentucky, and West Valley, New York disposal facilities have been shown to contain elevated quantities of tritiated gaseous compounds, primarily CH_3T (methane) and HTO, but also HT and other tritiated hydrocarbons. Such C-14 tagged hydrocarbons as $^{14}CO_2$ and $^{14}CH_3$ have also been identified as well as Kr-85 and Rn-222.

Table M.1 is a summary of radionuclide concentrations and gas composition in samples of trench sump gas at the West Valley facility. Also shown are the results of the analysis of a single sample of soil gas over a fractured area in the cap over trench no. 3. This sample was obtained through collection of gas accumulated underneath a plastic tarpaulin placed over the fractured area. The most abundant radioactive species in the trench gas was tritium as CH_3T, which constituted 22-68% of the sump gases (Ref. 2). Lu and Matuszek also developed an empirical method to estimate the bulk permeability of disposal trench covers to estimate rates of gas production and gas release. This was determined by measuring the pressure differential between trench gas and the atmosphere, and correlating the measured pressure differentials measured in the field with those calculated through a Darcy-Flow Model, GASFLO. Using this method, the annual volume of gas released to the environment (which can vary depending upon seasonal climatic changes) was estimated. This gas volume was then multiplied by the measured gas concentrations in disposal trench sumps and annual radionuclide release rates determined. Lu and Matuszek calculated that the amount of TCH_3 released to the environment could be estimated to be approximately 1 to 8 curies per year from various West Valley disposal trenches (Refs. 3, 4).

Gas samples taken from trench sump monitoring wells are an indication of the nature of the gaseous source term, but may not indicate the magnitude of the gaseous emanation through a disposal trench cover. The actual concentration of radionuclides emanating from a disposal trench cover are of more significance to potential offsite exposures to the public. For example, the data from the West Valley disposal facility indicates that the concentration of tritium emanating from a trench (in pCi/cc of air) may be a factor of 1000 less than tritium concentrations measured from a trench sump well. Similarly, the concentration of C-14 emanating from a disposal trench may be a factor of 10 to 140 less.

Since the acquisition of the West Valley, New York data, experimental measurements of tritium and C-14 concentrations in gases emanating from disposal trenches have been made at the Maxey Flats, Kentucky (Ref. 5) and Beatty, Nevada (Ref. 6) disposal facilities. These measurements provide a comparison of gas concentrations in trench wells and trench covers at both a humid and an arid disposal facility. Measurements of Rn-222 fluxes (in pCi/m^2-sec) emanating from disposal trench covers have also been made at the Maxey Flats and Beatty facilities.

Samples were collected at these facilities from trench sump wells in addition to soil gas samples. As the Beatty facility is located in an arid environment, the sump wells are all dry. In addition, samples were obtained at the Beatty facility from dry observation wells located between some of the disposal

Table M.1 Radionuclide Concentrations and Gas Composition in Trench Gas and Soil Gas Samples at West Valley, New York.

Concentration (pCi/cc)	Well 2-1A	Well 3-1	Well 5-1A	Well 5-3A	Trench 3 soil gas
HT	1.30 ± 0.12	8.2 ± 0.5	0.53 ± 0.08		<.0013
^{85}Kr	3.7 ± 1.4	3.9 ± 0.6	40 ± 2		0.0027 ± 0.0003
$^{14}CH_4$	5.5 ± 0.9	2.0 ± 0.2	6.4 ± 0.9	96 ± 12	0.7 ± 0.1
CH_3	130 ± 0.2	250 ± 30	480 ± 50	1580 ± 160	0.110 ± 0.111
$^{14}CH(HC)$	1.1 ± 0.4	0.4 ± 0.2	<0.16		
$^{3}H(HC)$	2.5 ± 0.8	29 ± 3	47 ± 5		
^{14}CO	0.06 ± 0.03		0.19 ± 0.03		
$^{14}CO_2$	2.2 ± 1.0	0.9 ± 0.4	7.4 ± 1.5	4.8 ± 0.3	0.0067 ± 0.0008
^{14}C (total)	6.7 ± 1.5	15 ± 0.9	26 ± 7		
^{222}Rn	2.56 ± 1.10	83 ± 3	0.94 ± 0.03	35.5 ± 1.1	0.117 ± 0.005
Gas Composition (%)					
N_2	62.0	67.0	63.6	25.8	79.1
O_2	0.22	0.70	3.5	0.12	19.7
CO_2	10.35	2.82	10.3	4.52	0.22
CH_4	26.7	28.7	21.8	68.3	<0.02
Ar	0.73	0.76	0.69	0.37	9.93
H_2	<0.03	<0.3	<0.4	0.84	<0.02

trenches. Sump samples at both facilities were obtained by pumping air from the sumps which was then either compressed into air cylinders or collected (relatively uncompressed) into 15-liter air sample collection bags. To determine concentrations of radionuclides in soil gas, accumulation canisters constructed of 55-gallon steel drums were used. The drums were sealed to the soil through use of water-emulsified polymer sealant and draped with thermal aluminized space blankets. Similar to the sump samples, air withdrawn from the soil gas accumulation canisters was collected into compressed air cylinders and uncompressed sample bags.

The results of these experimental measurements are shown in Tables M.2 through M.5. The results of the gas composition analyses for the two facilities are

Table M.2 Composition of Trench and Soil Gas at the Maxey Flats Disposal Facility

Location	N_2 (% Volume)	O_2 (% Volume)	CO_2 (PPM)	CH_4 (PPM)	Trace H_2O (mg/l)
Background					
North Fence	77	22	98	2	0.95
South Fence	77	22	168	2	2.11
Trench Gas					
TR-7 Sump	77	22	148	2	1.48
TR-11S Sump	77	22	470	114	2.60
TR-18 Sump	78	20	12000	6720	2.56
TR-26 Sump	77	22	29	2	2.22
TR-35 Sump	77	22	186	8	1.38
Soil Gas					
TR-11S	77	22	255	1	1.04
TR-18	77	21	2580	12	1.33
TR-20	78	22	881	1.4	1.47
TR-26	77	22	819	2	2.12
TR-35	77	22	1410	4	2.83
Natural Dry Atmospheric Air	78.1	20.9	315	1.2	--

Table M.3 Composition of Trench and Soil Gas at the Beatty Disposal Facility

	N_2 (% Volume)	O_2 (% Volume)	CO_2 (PPM)	CH_4 (PPM)	Trace H_2O (mg/liter)
Background	78	22	300	10	1.95
Observation Well R-1	78	20	1860	7.7	2.81
Observation Well R-2	78	17	8100	19	2.74
Observation Well R-3	74	15	1270	41	2.55
Observation Well R-6	78	22	600	7	N.A.
Sump Well TR-14	76	21	530	16	2.88
Sump Well TR-16	64	17	2200	9.80	3.59
Canister TR-2	73	21	300	5.1	1.77
Canister TR-3	77	22	300	7.1	2.11
Canister TR-4	76	21	300	6.5	2.08
Canister TR-5	73	21	300	6.5	2.02
Canister TR-14	79	21	300	6.5	2.02
Canister TR-16	78	22	300	7.3	2.58

Table M.4 Tritium and Carbon-14 Activity in Trench and Soil Gas (pCi/cc) at the Maxey Flats Disposal Facility

	Gaseous Tritium	HTO Tritium	Gaseous C-14
Background			
North Fence	4.18±0.18 (E-2)	2.48±0.11 (E-3)	0±0.45 (E-4)
South Fence	1.28±0.06 (E-2)	8.33±0.45 (E-3)	0±0.45 (E-4)
Trench Gas			
TR-7 Sump	1.29±0.07 (E-2)	6.31±0.34 (E-3)	0±0.45 (E-4)
TR-11S Sump	1.58±0.11 (E-2)	1.48±0.08 (E-2)	4.95±3.15 (E-5)
TR-18 Sump	1.12±0.07 (E-1)	2.25±0.22 (E-2)	7.88±0.33 (E-2)
TR-26 Sump	1.61±0.09 (E-2)	2.25±0.11 (E-3)	0±0.45 (E-4)
Soil Gas			
TR-11S	2.84±0.09 (E-3)	8.67±0.47 (E-4)	0±0.45 (E-4)
TR-18	9.01±0.90 (E-4)	6.42±0.34 (E-4)	4.50±3.15 (E-5)
TR-20	1.13±0.05 (E-2)	2.59±0.11 (E-3)	0±0.45 (E-1)
TR-26	5.81±0.36 (E-3)	4.95±0.23 (E-4)	0±0.45 (E-4)
TR-35	9.50±0.45 (E-3)	1.80±0.09 (E-3)	0±0.45 (E-4)

Table M.5 Tritium and C-14 Activity Measurements at the Beatty, Nevada Disposal Facility

	Gaseous Tritium (pCi/cc)	HTO Vapor (pCi/cc)	C-14 (pCi/cc)
Background	<1.35 (E-4)	5.52 (E-2)	<9.01 (E-5)
Trench Gas			
Observation Well R-1	2.68 (E-1)	8.22 (E-2)	5.90 (E-2)
Observation Well R-2	5.68 (E-3)	3.08 (E-2)	3.60 (E-2)
Observation Well R-3	4.73 (E-2)	2.93 (E-2)	3.04 (E-2)
Observation Well R-6	2.11 (E-1)	--	1.46 (E-3)
Sump Well TR-14	9.86 (E-2)	5.52 (E+0)	2.59 (E-2)
Sump Well TR-16	9.82 (E-1)	9.35 (E-2)	8.56 (E-3)
Soil Gas			
Canister TR-2	<1.35 (E-4)	5.18 (E-2)	<9.01 (E-5)
Canister TR-3	1.99 (E-1)	1.90 (E-2)	2.21 (E-4)
Canister TR-4	1.17 (E-1)	7.55 (E-2)	1.35 (E-4)
Canister TR-5	7.75 (E-2)	1.27 (E-2)	5.27 (E-3)
Canister TR-14	1.53 (E-1)	3.72 (E-2)	5.41 (E-4)
Canister TR-16	1.98 (E-1)	1.62 (E-2)	8.11 (E-4)

shown in Tables M.2 and M.3. Tritiated water vapor, gaseous tritium (all tritiated gas compounds except water vapor), and gaseous C-14 results for the Maxey Flats and Beatty facilities are shown in Tables M.4 and M.5, respectively.

The data is limited and there are a number of environmental and sampling variables which may not totally have been taken into consideration, such as the extent to which the sampling process itself changes the conditions to be measured. However, methane generation at the Beatty facility appears to be generally significantly less than that at West Valley or Maxey Flats. Measured concentrations of gaseous tritium and HTO vapor in the trench sumps at Maxey Flats appear to be elevated. However, concentrations of these radionuclides measured emanating from trench covers are significantly less--e.g., on the order of background concentrations at this disposal facility or less. Except for one sump measurement (trench-18), C-14 measurements at the trench sumps are consistent with C-14 concentrations measured in soil gas.

At the Beatty facility, elevated concentrations of C-14 are observed at the observation wells and the dry sumps; however, reduced C-14 concentrations are observed in soil gas. Also of interest is the observation that similar concentrations of C-14 are observed in the observation wells as in the trench sumps, which may mean that lateral diffusion of C-14 is taking place beneath the facility. A similar situation is observed for gaseous tritium and HTO vapor. For gaseous tritium, similar concentrations of gaseous tritium is observed at the observation wells, sump wells, and accumulation canisters. Except for one abnormally large measurement at sump well TR-14, all measured concentrations of tritium as HTO vapor lie within a relatively small range--i.e., from 1.27 to 9.35 E-2 μCi/cc. It may also be observed that while C-14 concentrations in the soil gas at the Beatty facility are about the same as those concentrations measured at Maxey Flats, gaseous tritium and HTO vapor soil gas concentrations are generally higher at Beatty than at Maxey Flats. This may be caused by the higher evapotranspiration at the Beatty facility, in addition to trench covers having higher permeability.

It is of interest to compare the concentrations of tritium and C-14 measured in soil gas to maximum permissible concentrations (mpc) for release to unrestricted areas listed in Table II of 10 CFR Part 20. For submersion doses, which would be the case here, the mpc for tritium is 4×10^{-5} μCi/ml while the mpc for C-14 is 1×10^{-6} μCi/ml (for CO_2). Taking the maximum H-3 and C-14 concentrations observed at the Beatty facility--i.e., 0.2 μCi/cc gaseous tritium and 5.27×10^{-3} μCi/cc C-14--the maximum observed concentrations are a factor of 200 below mpc for H-3 and a factor of 5300 below mpc for C-14. Concentrations in unrestricted areas would be much less due to atmospheric dispersion.

Radon-222 fluxes measured at the Maxey Flats facility ranged from negligible levels to 0.095 pCi/m^2-sec. These levels, however, were determined in the month of December, when generally wet conditions existed at the facility. Radon-222 flux measurements at the Beatty facility ranged from background (approximately 0.48 pCi/m^2-sec) to about 0.9 pCi/m^2-sec. By contrast, typical Rn-222 flux measurements from a bare uranium milling tailings pile are estimated at about 281 pCi/m^2-sec (Ref. 7). The proposed radon flux limit for reclaimed tailings is 2 pCi/m^2-sec. Table M.6 presents a list of typical radon flux measurements for various parts of the country (Ref. 7).

There are two concerns due to the observed generation of waste decomposition gases within disposal trenches: (1) offsite exposures due to release of radioactive gases, and (2) onsite nonradiological safety to operating crews.

In the former case, potential offsite releases and exposures to individuals would not appear to be significant. Although the existing data is limited, the emanation rates that have been measured at near-surface disposal facilities are small, and would indicate that potential offsite exposures would not be significant. That is, potential exposures would be expected to be orders of magnitude less than limits established in 10 CFR 20 and much less than limits established in 40 CFR 190 for effluents from operation of a nuclear fuel cycle facility. However, additional field investigation should be performed to verify this and to investigate the extent that differences in site design, operation, site climate, seasonal variation, measurement techniques, etc. have upon the emanation rates. For example, the observed differences in tritium emanation rates between the Beatty facility and the Maxey Flats facility may be due to the lesser permeability of the cover material at the Maxey Flats facility. As

Table M.6 Radon-222 Flux Measurements in the Contiguous United States

Location	Average Reported Radon Flux pCi/m²-sec
Illinois	
Champaign County (472)*	1.4
Argonne (8)	0.56
Massachusetts	
Lincoln (10)	1.34
New Mexico	
Socorro (10)	0.90
Socorro (6)	1.01
Socorro (164)	0.64
Nevada	
Yucca Flats	0.47
Texas	
Varied Locations (9)	0.27

*Number in parentheses indicates number of separate measurements.

mentioned earlier, the soil was generally saturated when the measurements were taken, which would impede upward gas flow. Other site specific conditions--such as the greatly increased evapotranspiration at the Beatty facility compared with the Maxey Flats facility--may also have an impact.

It is expected that the performance objectives established in Chapter 5 to reduce or eliminate the requirement for active long-term maintenance activities following disposal facility closure will also act to significantly reduce radionuclide emanation rates from trench covers--particularly from disposal facilities located in humid environments.

Decomposition of organic waste and generation of gases are complex processes accelerated by moist, saturated conditions and retarded by dry, unsaturated conditions. The former is illustrated by the conditions at Maxey Flats and West Valley facilities, where waste decomposition has led to increased infiltration and saturated conditions, further accelerating decomposition. The latter situation is illustrated by the Beatty, Nevada facility, which has no water management problems and a greatly reduced rate of waste decomposition. Emanation of the generated gases through the trench cap is a variable depending upon such factors as trench cap thickness and composition. In general, emanation rates would be reduced by thicker covers composed of lower permeable materials.

Key variables, of course, are the composition of the waste material itself, as well as the disposal practices at a particular site. Compressible, easily degradable organic waste material can lead to water management problems at humid sites as well as increased generation of gaseous decomposition products. It, therefore, can be deduced that essentially the same improvements in waste form and disposal facility design and operating practices that would eliminate the need for active long-term maintenance activities following site closure would also act to greatly reduce the rate of decomposition of the waste material. Such a reduction in the decomposition rate of the disposed waste would not only reduce the instanteous rate of gaseous decomposition products, but would also allow time for decay of the tritium (half life of about 12.3 years), which is the most significant radionuclide in terms of total curies. Thus, total integrated releases over time would be smaller.

In summary, the emanation rates actually measured from LLW disposal sites are very small, and would be expected to result in offsite doses which are expected to be considerably less than, for example, the 25 mrem/year whole body criteria proposed for protection of ground water at the facility boundary. Even under less than ideal conditions--that is, for example, at Maxey Flats where decomposing waste has produced a bathtub situation--decomposition gases have not resulted in significant releases. Furthermore, such generation rates would be expected to fall off over time. This is the experience seen by EPA for methane generation at nonradioactive solid waste disposal sites.

The principal long-term impact of a potential waste decomposition problem is probably not the gas emanation per se, but a potential problem with long-term active site maintenance, and has already been addressed as a performance objective. It should also be noted that the recent establishment of a de minimis or exempt level for tritium and C-14 contained in liquid scintillation fluid and biological waste would probably reduce the potential for active long-term site maintenance as well as reduce the generation of gaseous decomposition products at LLW sites (Ref. 8).

The second area of concern is of a relatively shorter-term nature--i.e., a potential nonradiological safety hazard at the disposal facility from generation of methane gas. Methane explosions have been observed at or nearby sanitary landfills (Ref. 9). This potential concern, however, can be mitigated or eliminated at a low-level waste disposal facility by, for example, reducing the decomposition rate of the waste material. This has already been shown to be important for minimizing the need for active long-term maintenance. In addition, methane gas generation and migration in sumps and observation wells may be readily monitored through currently available techniques. If monitoring shows methane gas generation to be a problem, the technology for construction of engineered control systems has already been developed for sanitary landfills and chemical and hazardous waste disposal facilities, where methane generation would be expected to be a much greater problem due to the nature of the disposal technology utilized and the typically higher organic content of the disposed waste material. Application of a given methane gas control technology would be applied if necessary on a site-specific basis as part of licensing an individual facility.

2. POTENTIAL FOR PLANT AND ANIMAL INTRUSION

Another potential source of long-term environmental releases is through potential intrusion of burrowing animals and deep-rooted plants into disposed waste. As discussed in Appendix F, a number of isolated cases of plant and animal intrusion into disposed waste have been documented (principally at government facilities). However, the existing information indicates that the past instances of plant and animal intrusion have not resulted in a significant public health and safety problem. Nonetheless, methods by which the potential impacts of plant and animal intrusion may be minimized are of interest to this environmental impact statement.

There appear to be three principal pathways in which potential intrusion of deep-rooted plants and burrowing animals can impact humans:

- Plant and animal intrusion can create pathways in a disposal trench cover for increased percolation of rainwater into the disposal trench, thus potentially increasing ground-water migration.

- Radionuclides may be brought to the surface where they may be dispersed by wind and water.

- Contamination on or within plants and animals may be potentially eaten by humans.

The first pathway is believed to probably be the most significant as it can potentially affect a larger population than the other two pathways. The effects of increased percolation of rainwater into disposal trench covers due to intrusion has already been included in the groundwater impacts calculation in Chapter 5. That is, for the cases in the case study that improved disposal trench covers are implemented, the maximum effectiveness of the improved covers is assumed only for a period of 100 years (active institutional control period) following facility license termination. During this time period, the site owner would maintain the facility and control access to it. Site maintenance activities would include surveillance for and control of potential presence of deep-rooted plants and burrowing animals. Following 100 years, some degradation in effectiveness of the disposal cell covers is assumed to occur due to the potential for inadvertent human intrusion, and the potential presence of deep-rooted plants and burrowing animals.

The other two pathways are believed to be less significant and would be bounded by the individual and population impacts calculated for potential human intrusion.

A consideration is that potential impacts of plant and animal intrusion into disposed wastes are highly site-specific and are, furthermore, difficult to calculate. Some of the factors which greatly influence potential impacts include:

- The climate of the disposal site.
- The varieties of plants and animals indigenous to the disposal site.
- The characteristics of the disposal operations.
- The characteristics of the disposed wastes (e.g., higher potential impacts would be expected from wastes having higher radionuclide contents, and/or wastes with higher potential for leaching or dispersion).

This indicates that the best approach may be to address ways to minimize plant and animal intrusion on a case-by-case basis as part of licensing individual disposal facilities. It is useful, however, to consider on a generic basis ways in which this may be accomplished.

It appears that many of the potential methods which can be used to minimize plant and animal intrusion or to reduce the impacts of such potential intrusion are similar or identical to those which are useful against potential human intrusion. For example, the potential for (and resulting impacts from) plant and animal intrusion can be minimized by:

- Institutional controls;
- Waste form and packaging; and
- Facility design and operating practices.

As discussed earlier, the site owner would be expected as part of institutional control to maintain control over the closed facility, and would carry out monitoring and surveillance activities as well as minor maintenance of site grounds. These activities would include control of undesirable vegetation and burrowing animals. Such activities, of course, would be a long-term expense to the facility owner, and it is desirable to minimize these long-term expenses.

The gain from improved waste forms and waste packages is straightforward. Improving waste form and packaging reduces the potential for leaching of the radionuclides out of the waste and subsequent migration or uptake by plant roots. In addition, the waste would be less likely to be in a form which could be brought to the surface by burrowing animals and dispersed.

Some facility design and operating practices which would tend to generally reduce the potential for plant and animal intrusion include the following:

- Increasing the thickness of earthen fill between the top of the disposed waste and the facility surface.

- o Placing higher activity material at greater depths (layering the higher activity waste).
- o Filling the interstitial spaces between the disposed waste containers with cement grout.
- o Use of barriers to intrusion (bio-barriers).

The first three items are straightforward. The burrowing depths of most animals, except some insects, typically are not more than one or two meters. Increasing the cover thickness (e.g., from one to two meters to three to four meters) would therefore place the waste below the burrowing depths of most burrowing animals. Layering the higher activity waste streams essentially eliminates the potential for intrusion into these waste streams. Contact, if it occurs, would be only with the lower activity waste streams. Grouting the disposed waste packages impedes intrusion into the disposal cells, reduces the potential for waste dispersion, and reduces the potential for increased ground-water migration.

Barriers against intrusion may also be used. One barrier which has been used with success against intrusion by burrowing animals is emplacement of a hard surface such as rip-rap, cobbles, or asphalt over the top of disposal trenches. The hard surface greatly discourages or eliminates burrowing mammals and has the added benefit of controlling potential wind and water erosion. Coatings of cobbles over filled disposal trenches are currently being routinely used at the Hanford Reservation, both at the disposal areas operated by DOE and the commercial disposal facility located within the reservation.

Over the past several years, work on development of biological barriers effective against deep rooted plants and burrowing insects in addition to burrowing mammals has been performed by Cline, et al., and this work is discussed in some detail in Appendix F. This work has included use of asphalt and cobble layers, as well as use of root toxins placed at sufficient depth below the surface to kill deep-rooted plants but allow shallow-rooted plants to grow. It is possible that herbicides could be used which would be nontoxic to the plant but would inhibit root growth.

To summarize Appendix F, the use of cobbles, asphalt, or other hardened layers would appear to be straightforward in application against intrusion by burrowing mammals. Additional work is required, however, to develop effective biological barriers against intrusion by plant roots, particularly in humid environments. In any case, construction of elaborate biological barriers could prove to be an expensive hinderance as long as trench subsidence was in evidence at a disposal facility. Subsidence would tend to crack rigid surfaces such as asphalt layers or concrete, thus reducing or eliminating their effectiveness. Repairs or restabilization activities would also tend to be more difficult and more expensive.

3. EROSION

Another source of potential environmental releases is through the effects of wind and water erosion. Through these mechanisms, the covers over disposal trenches may be removed over time, eventually exposing the disposed wastes which then could be potentially dispersed into the environment through airborne or waterborne pathways. In addition, a significant erosion problem would reduce the ability to predict disposal facility impacts over time.

It is recognized that minimizing the effects of erosion is of significant importance when siting, designing and operating a disposal facility. The effects of erosion are site-specific and would be analyzed as part of individual licensing actions for a particular disposal facility. For some facilities--for example those located in an arid region having high winds--wind erosion may be of most significance. For facilities located in humid environments, gully or sheet erosion due to the action of water may be of most significance. Gully erosion would affect less of the disposed waste, but could occur over a shorter time frame. Sheet erosion would eventually effect a larger area, and hence a larger amount of the disposed waste, but would take longer to occur.

It is believed that the effects of erosion at a disposal facility can be minimized through proper siting, design, and operation to the point that it needn't be considered a problem. Practical measures which can be readily taken to minimize or eliminate this potential problem include the following examples:

- Avoid areas characterized by rapid erosion, such as floodplains, areas of high topographic relief, and so forth.
- Stabilize the site against erosion through application of a soil cover such as grass or a layer of rip-rap.
- If drainage channels are used at the facility, minimize gully erosion through appropriate engineering such as lining with rip-rap.

Still, it is difficult to predict the effectiveness of measures intended to minimize erosion over the long term, and it is instructive to obtain an upper-bound estimate of the level of potential exposures that could occur if through some reason the waste did become exposed through erosion. To do this, an estimate must be made of the length of time that it takes for the cover over the waste to be removed through weathering activities. As stated above, gully erosion could be a fairly rapid process. However, its effects would tend to be localized and if it were to occur, then it would probably occur during the 100-year institutional control period. During this time period, the disposal site would be under the surveillance and control of a governmental agency and steps could be taken to correct the problem. Sheet erosion, however, would appear to be a less perceptible, long-term potential problem.

3.1 Water Erosion

A short but illustrative discussion of soil-water erosion rates is provided by Healy and Rodgers in Reference 10. As observed by the authors, erosion rates can vary widely depending upon such site-specific factors as rainfall, soil type, ground slope, soil cover, and human activities. To calculate the potential erosion rate, use may be made of the universal soils loss equation (USLE). This equation has been used (or a derivative has been used) for a number of years to estimate erosion rates from plowed agricultural fields. A derivative of the semi-emperical equation has also been used to determine erosion rates during highway and other forms of construction activities. As stated above, the equation is actually intended for use in determining erosion from plowed agricultural fields. The length of time over which the erosion rate is calculated is short and the conditions under which the equation is used (e.g., plowed fields) are those in which sheet erosion would be accentuated. Considerable care must be taken when applying the equation to a disposal facility. Still, the equation is useful as a basis of discussion of the variation in erosion rates and the types of factors which influence erosion rate.

A simplified derivative of the universal soil loss equation is as follows (Ref. 11):

A = R x K x LS x VM, where

A = The computed soil loss in tons/acre per year. This quantity may be converted to cubic meters using selected conversion factors.

B = The rainfall intensity factor, which is a measure of the erosion force of rainfall.

K = The soil erodibility factor, which is highly regional.

The next two parameters are of importance as they may be varied to control and minimize erosion:

LS = The topographic factor--e.g., the effect of length and steepness of slopes on the soil loss per unit area.

VM = The erosion control factor, which is a function of all erosion control measures such as vegetation, mechanical manipulation of the surface, chemical treatments, etc. For bare slopes, VM=1.

In general, a maximum rate of erosion is apparently reached in areas having precipitation on the order of 25 cm/yr (10 in/yr), with decreased rates in more humid as well as in more arid climates. The number and severity of rain storms is also an important factor. To determine the effect of rainfall, a rainfall erosion-index (or rainfall intensity factor) has been developed, which is a function of the total kinetic energy of a rainstorm as well as its maximum intensity over a 30-minute period. Iso-erodent maps are available giving regional values of this index and in the eastern states, this factor can vary from about 50 to about 600.

The soil erodibility factor accounts for the differences in erosion potential among different soils. This factor can vary widely--e.g., from 0.69 for a Dunkirk silt loam to 0.03 for an Albin gravelly loam (Ref. 10).

Of course, the gradient of the ground slope as well as the steepness of the ground slope are also important factors. Complicated formulas can be used to determine the topographic factor for multiple slope lengths and gradients. One such formula is illustrated in Reference 11. In general, however, the factor is larger with larger gradients. Healy and Rodgers gives an example of this in Reference 10. "For a length of 60 m (200 ft.), the soil loss ratio varies from about 0.3 at a 2% gradient to about 6 at a slope of 20%."

The last factor--the erosion control (soil cover) factor--greatly influences the calculated erosion rate. For agricultural purposes, determining this factor can be complicated. It may, for example, be influenced by such factors as crop management techniques, growth stages of crops during periods of heavy rainfall, and so forth. However, as stated in Reference 10, "with established meadows of grass, alfalfa or clover, the soil loss rates are 0.4 to 2% of that from fallow land."

For purposes of waste management, this implies that a good soil cover over a disposal facility such as a thick vegetative carpet or a layer of rip-rap can reduce potential erosion rates from a given site (all other factors such as rainfall, soil erodibility, and topography being equal) by 2 or 3 orders of magnitude.

The combined effect of the different possible rainfall, soil erodibility, topography and soil cover factors can result in wide differences in erosion rates. For example, Table M.7, obtained from Reference 10, provides an illustration of different erosion and runoff rates for a number of widely scattered soil types, rainfall, crops, and so forth. The erosion rate of clean tillage can exceed that associated with dense soil covers by 2 to nearly 3 orders of magnitude.

Human activities such as construction of houses or roads can result in greater erosion rates with respect to agricultural activities while erosion rates associated with natural weathering activities are generally in a lower range. Table M.8, obtained from Reference 10, illustrates this. As can be seen, erosion rates from construction activities can be quite high. However, such erosion rates would only be temporary and after construction had ceased, erosion rates would quickly fall to much lower levels--perhaps to levels below those associated with preconstruction. Erosion rates for clean tilled farming activities can also be high (e.g., on the range of 10-60 tons per acre per year). However, it is again unlikely that such erosion rates would occur over long time periods. Continued erosion rates of that magnitude would result in a rapid loss in productivity of the farmland.

Natural erosion rates are an estimate based upon consideration of the volume of deposits in closed systems.

Given the above discussion it would appear that while the potential for water erosion is an important consideration for radioactive waste disposal, it is a site-specific phenomenon and can best be regulated as part of licensing actions for a specific disposal facility. However, it is useful on a generic basis to determine the range of potential exposures that could occur over the long term at the reference facility. To do this, an estimate must be made of the length of time that it would take for the disposal cell covers to be removed. One

Table M.7 Annual Soil and Water Losses per Acre from Five Widely Separated Types of Land Under Conditions of Clean Tillage and Dense Cover of Vegetation*

			Clean-Tilled Crop		Dense Cover-Thick-Growing Crop		Approximate Number of Years to Remove 18 cm of Soil	
Soil, Location and Years of Measurements	Average Annual Precipitation	Slope	Annual Soil Loss	Annual Water Runoff**	Annual Soil Loss	Annual Water Runoff**	Clean Tillage	Dense Cover
	(cm)	(%)	(tons)	(%)	(tons)	(%)		
Shelby silt loam, Bethany, MO, 1931-35.	88	8.0	68.78	28.31	0.29	9.30	16	3,900
Kirvin fine sandy loam, Tyler, TX, 1931-36.	104	8.75	27.95	20.92	0.124	1.15	49	11,100
Vernon fine sandy loam, Guthrie, OK, 1930-35.	84	7.7	24.29	14.22	0.032	1.23	50	38,200
Marshall silt loam, Clarinda, IA, 1933-35.	68	9.0	18.82	8.64	0.06	0.97	48	15,200
Cecil Clay loam, Statesville, NC, 1931-35.	115	10.0	22.58	10.21	0.012	0.33	51	95,800

*Measurements at the soil and water conservation experiment stations of the Soil Conservation Service.

**Of total precipitation.

Table M.8 Erosion Rates Under Varying Conditions

Soil or Rock Description	Use	Erosion Rate
		(tons/acre per year)
Igneous rock	Geologic past	0.08
Appalacian Mountains	Geologic past	0.7
Midcontinent farmland	Typical farming (other than clean tilled)	0.5-6
	Clean tilled	10-60
Urban or suburban	During construction	70-200

reference, (Ref. 12) in considering this question, postulated a range of one to six tons of soil lost per year. Reference 10 also assumed a range of one to six tons a year, and based on a bulk density for soil of 1.5 gm/cm^3, postulated a time period of from 2,000 to 13,000 years to remove 2 meters of soil cover over disposed waste.

Similarly, for purposes of this environmental impact statement, a time of 2,000 years is assumed to be required to uncover 2 meters of soil, or about 1,000 years per meter of cover over the disposed waste. This essentially assumes a soil loss of 6 tons per acre per year from the disposal trench. A continual (over 2,000 years) soil loss rate of this magnitude from the disposal facility is extremely unlikely. It ignores ground cover and other surface engineering measures that would be incorporated into the disposal facility design. The loss rate is at an upper range associated with typical farming activities. Such farming activities are unlikely to occur and if they do occur, it would be unlikely that a continual soil loss rate of 6 tons per year would be tolerated by a farmer. Such rates would probably reduce the productivity of the soils to unacceptable levels long before the 2 meters of soil thickness is lost.

In any case, after a time period equal to 1,000 years per meter of cover thickness, the trench covers are hypothetically assumed to be eroded away and the scenario is initiated. As a further conservatism, no credit for waste form is assumed for the erosion scenario. Neither is credit taken for barriers against erosion such as a rock cover or more elaborate measures such as disposing of the waste in walled trenches. The contaminated exposed soil/waste mixture is assumed to be carried by the water into the surface body water located one kilometer from the disposal facility. The natural mobilization rate calculated for the reference facility (about 0.75 tons/acre/year) is used. The reduction in the activity due to deposition along the route is neglected and the soil/waste mixture is assumed to all dissolve in the surface water, where the water is used by an individual for consumption, crop irrigation, and so forth. The total exposures received by all significant pathways may be then calculated. Additional detail regarding the calculational procedure is provided in Appendix G.

Table M.9 presents the results of the calculations for each of the cases considered in the analysis carried out in Chapter 5 for ground-water migration. As discussed in Appendix G, the calculated exposures will vary depending upon such factors as the waste spectrum (e.g., the radionuclide concentrations), the disposal efficiency, the amount of land area exposed, the disposal cell cover thickness, and the density of the waste. Another factor is the placement of the waste to limit exposures to intruders--e.g., the amount of waste that must be layered to meet intruder exposure limitation requirements. In any case, all exposures seem to lie within a relatively small range. For example, exposures to all organs except thyroid range from about 0.05 mrem/yr to about 0.7 mrem/year. Exposures to the thyroid range from about 0.1 to 1 mrem/year. These calculated exposures are less (in some cases significantly less) than the 4 mrem/year limit for drinking water promulgated by the Environmental Protection Agency in 40 CFR 190. Given the conservatism of the calculational procedure, and the hypothetical nature of the institution's mechanisms (e.g., the facility would be sited and designed so that erosion would not be a problem), it is believed that actual waterborne erosional impacts would be much less.

It is also of interest to compare these calculated exposures to those corresponding to a "no action" case in regard to intruder exposures. In Chapter 4, "a base case" is considered in which no consideration is given to intruder exposures. Two waste streams included in this base case analysis--L-DECONRS and N-SOURCES--were excluded from cases 1 through 10 on Table M.9 due to the transuranic content of these streams. In addition, no consideration is given in the "no action case" to disposing of higher activity waste streams by methods, such as layering, that provide a barrier against intrusion. The corresponding waterborne erosion impacts are shown below in Table M.10 for waste spectrum 1. As can be seen, the calculated results for the base (no action) case are significantly higher (two orders of magnitude) for all organs except thyroid. In general, layering of the higher activity waste streams results in thyroid exposures of 10 less than the base case.

3.2 Wind Erosion

The mechanism for mobilization of particulates from soil by wind depends upon such factors as wind speed, soil properties, and the nature of the soil surface. Wind action results in three basic modes of particle motion: surface creep (particulates above approximately 500 μm in size), saltation (particles between approximately 100 μm and 500 μm in size), and airborne suspension (particles less than about 100 μm in size). Under surface creep, particles are rolled along the surface by the push of strong winds and by exchange of momentum after impact with smaller particles in saltation. Saltation consists of individual particles jumping and lurching within a few centimeters of the ground. Particles borne by airborne suspension may be carried through the atmosphere for long

Table M.9 Waterborne Radiological Impacts Assuming Erosion of the Facility Designs Considered in Chapter 5 Case Study

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(millirems/yr to an individual)							
1	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
2	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
3	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
1A	5.37E-2	4.64E-1	7.61E-2	1.19E-1	9.17E-2	4.26E-2	7.27E-2
4A	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4B	5.36E-2	4.63E-1	7.59E-2	1.19E-1	9.15E-2	4.25E-2	7.26E-2
4C	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
4D	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
4E	4.74E-2	4.15E-1	6.34E-2	1.14E-1	7.62E-2	3.78E-2	6.53E-2
5	5.23E-2	4.56E-1	9.06E-2	8.79E-1	6.11E-2	2.37E-2	1.17E-1
6	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
7A	6.42E-2	4.93E-1	7.81E-2	9.73E-2	9.73E-2	5.33E-2	8.13E-2
7B	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7C	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
7D	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
8	7.49E-2	6.35E-1	1.28E-1	9.82E-1	9.37E-2	4.02E-2	1.68E-1
9	4.69E-2	4.29E-1	8.52E-2	8.74E-1	5.57E-2	1.82E-2	1.11E-1
10A	4.74E-2	4.15E-1	6.35E-2	1.14E-1	7.63E-2	3.78E-2	6.53E-2
10B	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
10C	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1
12A	9.76E-2	7.76E-1	1.61E-1	1.00E+0	1.32E-1	6.04E-2	1.95E-1
12B	8.87E-2	7.03E-1	1.41E-1	9.94E-1	1.08E-1	5.41E-2	1.81E-1
12C	9.74E-2	7.75E-1	1.61E-1	9.98E-1	1.31E-1	6.03E-2	1.94E-1
12D	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1
12E	9.74E-2	7.75E-1	1.61E-1	9.98E-1	1.31E-1	6.03E-2	1.94E-1
12F	8.85E-2	7.01E-1	1.41E-1	9.92E-1	1.07E-1	5.40E-2	1.81E-1

Table M.10 Waterborne Erosion Impacts for the Base Case

Organ Exposures (millirem/yr)

Body	Bone	Liver	Thyroid	Kidney	Lung	GI
3.203	171.2	17.36	1.036	14.50	0.424	10.17

periods and to great distances from their original location. The mechanism by which fine particles are lifted off the ground is different from that of saltation. Samples of soil composed only of fine dust particles may be extremely resistant to wind erosion, but in mixtures with coarser grains these particles move readily. Thus, suspension of fine dust in air may be primarily the results of movement of grains in saltation (Ref. 7).

Calculational procedures are available to estimate the soil loss (in gm/m^2-sec) from an exposed area. Such calculations depend upon such factors as soil erodibility, soil-ridge roughness, climate, and the presence of a cover which would preclude or greatly reduce wind erosion. As in the case of water erosion, such covers could include application of a vegetative cover or a layer of gravel, rocks, or rip-rap. At the reference disposal facility, the soil loss for bare soil is calculated to be 4.1 E-7 g/m^2-sec. Assuming a soil density of 1.6 gm/cm^3 and a trench cover thickness of 2 meters, this implies that the wind erosion rate of a bare cover would be about 0.001 cm/yr. This would imply that it would take 250,000 years for the waste to become exposed. A longer period of time would be necessary to expose the waste if stabilizing soil covers such as a layer of rocks are applied.

However, for the purposes of bounding potential exposures due to water erosion, it was previously assumed that wastes would be exposed at a time period equal to 1,000 years per meter of cover. Given this assumption, a bounding estimate of the impacts of wind erosion at the reference disposal facility can be estimated. Similarly to the water erosion case, the equations for calculating total volume of soil/waste mixture assumed to be mobilized after a long time period (2,000 years for the reference case) are described in Appendix G.

Conservatively assuming no credit for waste form, the total population exposures within 50 miles of the facility are calculated for each of the case study cases in Chapter 5 and presented in Table M.11. The population is again assumed to be three times the size of the population within the vicinity of the facility while the facility is operating. As can be seen, such exposures are very small and are an order of magnitude or so below those exposures calculated during the hypothetical operation of a regional incinerator (1870 man-millirem/yr).

The exposures calculated and presented in Table M.11 can again be compared with those corresponding to the base (no action) case considered in Chapter 4. For random disposal, a thin cover, and waste spectrum 1, these exposures are calculated to be as shown in the following Table M.12.

Table M.11 Airborne Radiological Impacts Assuming Erosion of the Facility Designs Considered in Chapter 5 Case Study

	Organ						
Case	Body	Bone	Liver	Thyroid	Kidney	Lung	GI
(man-millirem/yr)							
1	4.19	80.13	55.32	5.38	21.21	76.43	0.21
2	4.19	80.13	55.32	5.38	21.21	76.43	0.21
3	4.19	80.13	55.32	5.38	21.21	76.43	0.21
1A	4.19	80.13	55.32	5.38	21.21	76.43	0.21
4A	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4B	4.19	80.01	55.24	5.37	21.18	76.31	0.21
4C	3.48	69.52	46.05	5.36	16.14	74.39	0.19
4D	3.48	69.46	46.01	5.35	16.13	74.33	0.19
4E	3.48	69.46	46.01	5.35	16.13	74.33	0.19
5	4.23	84.87	55.02	58.67	18.02	84.85	0.24
6	3.48	69.46	46.01	5.36	16.14	74.39	0.19
7A	3.11	59.29	40.19	3.17	15.21	70.66	0.23
7B	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7C	7.31	137.6	95.00	64.53	36.03	111.9	0.38
7D	6.11	119.8	79.40	64.51	27.50	108.6	0.35
8	6.09	119.8	79.50	64.58	27.51	108.8	0.32
9	4.22	84.81	55.01	58.66	18.01	84.84	0.22
10A	3.48	69.52	46.05	5.36	16.14	74.39	0.19
10B	6.11	119.8	79.40	64.51	27.50	108.6	0.35
10C	6.10	119.5	79.22	64.36	27.43	108.4	0.35

Table M.12 Airborne Erosion Impacts for the Base Case

Organ Exposures (man-millirems/yr)

Body	Bone	Liver	Thyroid	Kidney	Lung	GI
2.61E+3	5.48E+4	3.60E+4	65.80	1.18E+4	4.15E+4	54.28

The base case (no action) exposures are again seen to be one or more orders of magnitude higher.

REFERENCES

1. U.S. Environmental Protection Agency, Draft Environmental Impact Statement on the Proposed Guidelines for the Landfill Disposal of Solid Waste, Office of Solid Waste, March 1979.

2. Husain, L., J. M. Matuszek, J. Hutchinson, and M. Wahlen, Chemical and Radiochemical Character of a Low-Level Radioactive Waste Burial Site, Management of Low-Level Radioactive Waste, Vol. 2, Pergamon Press, 1979.

3. Lu, A. H,. and J. M. Matuszek, 1978, Transport through a Trench Cover of Gaseous Tritiated Compounds from Buried Radioactive Wastes, presented at the International Symposium on the Behavior of Tritium in the Environment, San Francisco, California, October 16-20, 1978.

4. Matuszek J. M., M. E. Wahlen, C. O. Kunz, and J. H. Hutchinson, 1978. Is the Removal of ^{14}C from Nuclear Reactor Effluents a Plausible Regulatory Practice?, presented at Conference on Effluent and Environmental Radiation Surveillance, Atlanta, Georgia, July 9-14, 1978.

5. Clancy, J., O. Oztunali, H. Tuchfeld, and T. Van Arsdale, Maxey Flats Facility Studies Progress Report No. 2, January-March 1979., Dames & Moore, May 1979.

6. Clancy, J., Trench Gas Study at the Beatty, Low-Level Radioactive Waste Disposal Site, Dames & Moore, October 1978.

7. U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, Office of Nuclear Material Safety and Safeguards, NUREG-0706, September 1980.

8. U. S. Nuclear Regulatory Commission, 10 CFR 20: Biomedical Waste Disposal, Federal Register, 46 FR 16230, March 11, 1981.

9. Stone, R., Controlling the Underground Movement of Methane from Sanitary Land Fills, Civil-Engineering-ASCE.

10. Healy, J. W., and J. C. Rodgers, Limits for the Department of Energy Transuranic Wastes, Los Alamos Scientific Laboratory, LA-UR-79-100,

11. Oztunali, O. I., G. Re', Cr J. Pitt., Data Base for Radioactive Waste Management: Volume 4, Impacts Analysis Methodology Report, NUREG/CR-1759, Dames & Moore for NRC, to be published in 1981.

12. Adam, J. A., and V. L. Rogers, A Classification System for Radioactive Waste Disposal--What Waste Goes Where?, NUREG-0456, Ford, Bacon, & Davis, Utah for NRC, June 1978.

Appendix N

ANALYSIS OF EXISTING RECOMMENDATIONS, REGULATIONS AND GUIDES

INTRODUCTION

This appendix reviews a number of proposed and promulgated NRC and EPA regulations and guidance which may be applicable to LLW disposal. Recommendations by the National Council on Radiation Protection and Measurements (NCRP), International Commission on Radiation Protection (ICRP), and the Federal Radiation Council (FRC) are also briefly reviewed. The regulations, recommendations, and guidance documents reviewed include those for radiation protection, surface contamination, ground-water protection, and disposal of solid and chemically hazardous waste.

1. NUCLEAR REGULATORY COMMISSION REGULATIONS

1.1 10 CFR 20: Standards for Protection Against Radiation

The NRC regulation, 10 CFR 20, provides standards for control of and limitations for release of radioactive materials to the environment from operations of NRC-licensed facilities, as well as limitations on allowable radiation doses to radiation workers and the public. The regulation was originally promulgated in the late 1950s, and has been subsequently revised a number of times. Although originally 10 CFR 20 was based on the recommendations of the NCRP and ICRP, subsequent guidance has been provided by the FRC. The FRC has been incorporated into the Environmental Protection Agency (EPA). NRC is currently considering a wholesale restructuring and modernization of the regulations. A Federal Register notice requesting public input on the potential areas of change was issued by NRC in March 1980 (Ref. 1).

The principal limits for exposure of radiation workers (exposure to individuals in restricted areas) are as follows:

Rems per Calendar Quarter		
1.	Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1-1/4
2.	Hands and forearms; feet and ankles	18-3/4
3.	Skin of whole body	7-1/2

However, an individual in a restricted area may receive a whole body dose up to and including 3 rems, provided that the whole body dose, when added to the accumulated occupational whole body dose, does not exceed 5 x (N - 18) rems. As used here, N equals the individual's age in years at his last birthday, and "whole body dose" is deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye. More restrictive requirements--that is, a factor of 10 lower--are in effect for individuals (minors) less than 18 years of age. The regulation also provides limits on airborne concentrations of radioactive materials in restricted areas.

Section 20.105 concerns permissible levels of radiation in unrestricted areas (0.5 rem/year to the whole body of any individual). In addition, paragraph 20.105(b) places limits on allowable hourly and weekly exposure rates to individuals in unrestricted areas. These are:

- o 2 mrem in any one hour; or

- o 100 mrem in any 7 consecutive days.

In addition, the regulation provides a table of maximum permissible concentrations (MPC) of radionuclides in air and water from releases to unrestricted areas. These MPC values are contained in Appendix B, Table II of the regulation and were calculated based upon a maximum potential dose to the whole body of an individual of 500 mrem/year. Limits for other organs include 500 mrem/yr to blood-forming organs, 3000 mrem/yr to bone surfaces, and 1500 mrem/yr to other organs except thyroid. For thyroid, a limit of 3000 mrem/yr was used except for exposures from radioiodine, for which a limit of 1500 mrem/yr to a child's thyroid was used.

Fairly recently, NRC published a proposed rule regarding amending its regulations to incorporate the existing requirement for certain uranium fuel cycle licensees to comply with the EPA regulation 40 CFR Part 190: "Environmental Radiation Protection Standards for Nuclear Power Operators." This rule requires that most uranium fuel cycle facilities be operated so that release of radioactive materials and resulting radiation doses to the public be below limits set in 40 CFR Part 190. (These limits are discussed in Appendix N, Section 2.2.) The proposed rule also requires licensees to submit reports to NRC when those standards have been or may be exceeded (Ref. 2).

Of importance for the standards for exposure to workers and to individuals in unrestricted areas is a further requirement that all potential exposures must not exceed the standards, but should also be maintained to levels "as low as reasonably achievable" (ALARA). This standard is applied in individual licensing actions to assess the licensee's operations. In the application of the standard, costs and other social considerations are taken into account.

Sections 20.106 and 20.301-20.305 of Part 20 contain requirements on radioactive waste disposal, where, as used in these paragraphs the term "disposal" may mean:

- o transfer to another authorized licensee (20.301);

- o disposal by a manner not otherwise authorized (20.302);

- o release into sanitary sewerage systems (20.303);

- o release in effluents to unrestricted areas (20.106 and 20.301); and
- o treatment or disposal by incineration (20.305).

In a recent modification to Part 20, NRC amended the requirements in Sections 20.301, 20.303, and 20.305, and added a new Section 20.306, to permit licensees greater leeway in disposal of some wastes (Ref. 4). In the rule, licensees are allowed to dispose of liquid scintillation media and animal carcass waste having concentrations of tritium or ^{14}C not in excess of 0.05 microcuries per gram without regard to its radioactivity. That is, such wastes may be disposed by such means as discharge into ordinary refuse channels (e.g., into a sanitary landfill) or, depending upon the chemical hazard of the waste, by disposal into a hazardous waste facility. In addition, the allowable annual quantities of tritium and ^{14}C disposed into the sanitary sewerage system was raised to five curies for tritium and one curie for ^{14}C.

Licensing of disposal of LLW into licensed burial facilities is currently accomplished through Section 20.302, as well as portions of Parts 30, 40, and 70. The regulations in Section 20.302, which provide only general guidance of an administrative nature, are quoted below:

> "20.302 Method for obtaining approval of proposed disposal procedures.
>
> "(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.
>
> "(b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the federal government or by a state government.
>
> "(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal."

Finally, 10 CFR 20 contains a number of other criteria and requirements related to radiation protection. These include requirements on surveys, personnel monitoring, and posting; requirements for records, reports, and notification; and requirements on receipt and shipment of packages containing radioactive material.

1.2 10 CFR 50, Appendix I: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low as is Reasonably Achievable" for Radioactive Material In Light-Water-Cooled Nuclear Power Reactor Effluents

This appendix provides an operator of a nuclear power plant with guidance regarding demonstration that the impacts of radioactive liquid and airborne effluents have been reduced to levels as low as is reasonably achievable (ALARA). Design objectives and limiting conditions of operation which correspond to the guidelines in the appendix are considered a conclusive demonstration that the ALARA requirement has been achieved. Information regarding the development of Appendix I can be found in Docket file RM-50-2 and in the final environmental statement on the rulemaking action (Ref. 5).

The design objectives and limiting conditions of operation for a reactor must be such that reasonable assurance is provided that the liquid and airborne effluents from the plant will not cause the annual dose or dose commitment to any person in an unrestricted area to exceed certain criteria. These criteria are:

- o Liquid effluent: 3 mrem to the total body or 10 mrem to any organ; and
- o Airborne effluent: 5 mrem to the total body or 15 mrem to the skin from effluent existing as a gas (for example, Kr-85); 15 mrem to any organ from radioactive iodine; or 15 mrem to any organ from particulate activity.

In addition to the criteria listed above, an applicant or operator shall "include in the radwaste system all items of reasonably demonstrated technology that, when added to the system sequentially and in order of diminishing cost-benefit return, can for a favorable cost-benefit ratio effect reduction in dose to the population reasonably expected to be within 50 miles of the reactor." As an interim measure, the values $1,000 per total body man-rem and $1,000 per man-thyroid-rem were proposed as values to use in the cost-benefit analysis.

1.3 10 CFR 100.11: Determination of Exclusion Area, Low Population Zone, and Population Center Distance

Dose limits are used in 10 CFR 100.11 for determination of reactor exclusion areas and low population zones. These limitations are 25 rem to the whole body or 300 rem to the thyroid from iodine exposure, assuming a major accident which results in release of appreciable quantities of fission products. As noted in 10 CFR 100, the whole body dose of 25 rems corresponds numerically to the maximum dose recommended by the National Council on Radiation Protection and Measurements (NCRP) for a once-in-a-lifetime accidental or emergency dose to radiation workers. The dose guides are intended as an aid in evaluating a proposed power reactor site with respect to potential reactor accidents of exceedingly low probability of occurrence, and low risk of public exposure to radiation. The dose limits set forth in 10 CFR 100.11 are not meant to imply that the numbers constitute acceptable limits for emergency doses to the public under accident conditions.

2. ENVIRONMENTAL PROTECTION AGENCY (EPA) RADIATION PROTECTION CRITERIA, STANDARDS, AND GUIDELINES

Since Reorganization Plan Number Three of 1970, the Environmental Protection Agency (EPA) has been responsible for providing federal radiation protection guidance and establishing generally applicable environmental standards. In so doing, EPA has taken over the functions of the Federal Radiation Council. Of special interest to NRC's development of radioactive waste management and disposal regulations is EPA's development of overall criteria and standards for waste disposal. In 1978, EPA issued a proposed set of general "umbrella" criteria applicable to all radioactive waste. These general criteria, discussed below, have not been finalized. EPA also intends to issue a set of numerical environmental standards for specific waste types over the next few years. As outlined in the Final Interagency Review Group Report to the President, EPA planned to develop the following specific standards (Ref. 5):

High-level waste (1979)

Transuranic waste - stable form (1979)

Interim guidance - active uranium mills (1979)

Inactive uranium mill tailings (1979)

Airborne pollutants associated with uranium mill tailings (1980)

Residual activity - decommissioning (1981)

Transuranic waste - other forms (1982)

Low-level waste - shallow land burial (1983)

Low-level waste - sea disposal container standard (1983)

Active uranium mill standard (1985)

Specific schedules for certain of these standards have been published in the Calendar of Federal Regulations published in the Federal Register. The April 27, 1981 issuance (46 FR 23692) does not list a specific schedule for the LLW standard. Based on discussion with EPA staff, however, the standard for LLW disposal by shallow land burial is scheduled to be published in draft in 1982 and in final in 1983 and the schedule will be published in the October Federal Register Calendar. The HLW standard has been drafted and is scheduled for publication shortly. Also of interest is EPA's interim standards for cleanup of inactive uranium mills and tailings. These standards, discussed below, were published in April 1980 and January 1981.

Other standards and guidance on radioactive materials issued by EPA and of interest to NRC's development of long-term performance objectives are:

- o 40 CFR 190: Environmental Radiation Protection Standards for Nuclear Power Operations; and
- o Proposed Federal Radiation Protection Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the Environment.

These standards and guides are also discussed below.

2.1 Proposed Recommendations for Federal Radiation Guidance: Criteria for Radioactive Waste

Proposed guidance for federal agencies regarding management or regulation of radioactive waste material were issued by the EPA in November 1978 (Ref. 7). Comments were requested from the public to be used in the formulation of the final criteria and recommendations to the President for approval. Final criteria are not planned by EPA.

The intent of the criteria was to establish the basic principles to be applied by federal agencies for the formulation of policies, plans, programs, and decisions involving the management and disposal of radioactive waste. The proposed guidelines issued by EPA included the following:

1. Radioactive materials should be considered radioactive wastes requiring control for environmental and public health protection if they have no designated product or resource value and: (a) are human-produced by nuclear fission or activation, fabricated from naturally occurring radioactive materials into discrete sources or, as a result of regulatory activities, are prohibited from uncontrolled discharge into the environment; or (b) contain diffuse naturally occurring radioactive materials that, if disposed into the biosphere, would increase exposure to humans above that which would occur due to the preexisting natural state of the area.

2. The fundamental goal for controlling any type of radioactive waste should be complete isolation over its hazardous lifetime. Controls which are based on institutional functions should not be relied upon for longer than 100 years to provide such isolation; radioactive wastes with a hazardous lifetime longer than 100 years should be controlled by as many engineered and natural barriers as are necessary.

3. Radiation protection requirements for radioactive wastes should be based primarily on an assessment of risk to individuals and populations; such assessments should be based on predetermined models and should examine at least the following factors:

   - o The amount and concentration of radioactive waste in a location and its physical, chemical, and radiological properties;

- o The projected effectiveness of alternative methods of control;

- o The potential adverse health effects on individuals and populations for a reasonable range of future population sizes and distributions, and of uses of land, air, water, and mineral resources for 10,000 years or any shorter period of hazardous persistence;

- o Estimates of environmental effects using general parameters or of health effects based on generalized assumptions for as long as the wastes pose a hazard to humans, when such estimates could influence the choice of a control option;

- o The probabilities of releases of radioactive materials to the general environment due to failures of natural or engineered barriers, loss of institutional controls, or intrusion; and

- o The uncertainties in the risk assessments and models used for determining them.

4. Any risks due to radioactive waste management or disposal activities should be deemed unacceptable unless it has been justified that the further reduction in risk that could be achieved by more complete isolation is impracticable on the basis of technical and social considerations; in addition, risks associated with any given method of control should be considered unacceptable if:

   - o Risks to a future generation are greater than those acceptable to the current generation;

   - o Probable events could result in adverse consequences greater than those of a comparable nature generally accepted by society; or

   - o The probabilities of highly adverse consequences are more than a small fraction of the probabilities of high consequence events associated with productive technologies which are accepted by society.

5. Locations for radioactive waste disposal should be chosen as to avoid adverse environmental and human impacts and, wherever practicable, to enhance isolation over time.

6. Certain additional procedures and techniques should also be applied to waste disposal systems which otherwise satisfy these criteria if use of these additional procedures and techniques provides a net improvement in environmental and public health protection. Among these are:

   - o Procedures or techniques designed to enhance the retrievability of the waste; and

- Passive methods of communicating to future people the potential hazards which could result from an accidental or intentional disturbance of disposed radioactive wastes.

2.2 40 CFR 190: Environmental Radiation Protection Standards for Nuclear Power Operations

This regulation provides environmental radiation dose standards for operations which are part of the uranium nuclear fuel cycle. Specifically excluded from this regulation are uranium mining operations, operations at waste disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered nonuranium special nuclear and byproduct materials from the cycle. Background information on the rationale for the standard can be found in the environmental statement on the rule (Ref. 8).

The standards state that operations in the nuclear fuel cycle shall be such to provide reasonable assurance that:

"(a) The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as a result of exposures to planned discharges of radioactive materials, radon and its daughters expected, to the general environment from uranium fuel cycle operations and to radiation from these operations.

(b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of ^{85}Kr, 5 millicuries of ^{129}I, and 0.5 millicuries combined ^{239}Pu and other alpha-emitting transuranic radionuclides with half-lives greater than one year."

The effective date of standard (a) above was December 1, 1979, except for doses arising from uranium milling operations (effective on December 1, 1980). The effective date of standard (b) above was December 1, 1979, except for ^{85}Kr and ^{129}I (effective on January 1, 1980).

2.3 Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the Environment

This guidance, proposed by the EPA in November 1977, provides radiation protection guidance to federal agencies for persons potentially exposed to transuranics in the environment as a result of existing or possible future planned contamination (Ref. 9). The proposed guidelines state that the recommendations should be used only for guidance on possible remedial actions in incidences of presently existing or possible future contamination from transuranic elements. The guidelines further state that the guidance should not be used by federal agencies as limits for planned releases of transuranic elements into the general environment.

The following is the text of the proposed numerical recommendations: "The annual alpha radiation dose rate to members of the critical segment of the exposed population as the result of exposure to transuranium elements in the general environment should not exceed either:

1. 1 millirad per year to the pulmonary lung; or

2. 3 millirad per year to the bone."

In the guideline, the "critical segment of the exposed population" means that group of persons within the exposed population receiving the highest radiation dose to the lung or bone.

EPA states that the dose limits contained in the guidelines should be applied above those levels currently existing in the environment as a result of fallout from the testing of atomic weapons. EPA believes that the guidelines will achieve adequate health protection for the small fraction of the total population at greatest risk from exposure of transuranic elements. EPA further states that the guidelines will therefore provide much greater protection to the vast majority of the population at lesser risk. As stated in the proposed guidance, "the risk at the proposed guidance level is estimated to be less than one chance in a million per year and less than 10 chances per hundred thousand in a lifetime that an individual would develop a cancer from continuous exposure at the stated dose rates."

2.4 40 CFR 192: Standards for Cleanup of Inactive Uranium Processing Sites

According to the requirements of Public Law 95-604 (The Uranium Mill Tailings Radiation Control Act of 1978, or UMTRCA), EPA must establish environmental standards for the cleanup of open lands and buildings contaminated with residual radioactive materials (mainly tailings) from inactive uranium processing sites. In accordance with the standards, the Department of Energy (DOE) must conduct remedial actions (also required by UMTRCA) for designated inactive uranium processing sites.

Based on this legislative mandate, the EPA issued on April 22, 1980 a set of interim cleanup standards for inactive uranium processing sites (Ref. 10). The issuance of the immediately effective interim standards will allow DOE to begin remedial actions on the inactive sites. On the same day, EPA also issued a Federal Register notice in which the interim standards were proposed as a rule (Ref. 11). Comments from the public were requested on the proposed standards. More recently, in January 1981, EPA published proposed disposal standards for the inactive sites. A draft environmental impact statement was prepared and was issued along with the proposed rule (Refs. 12, 13).

The proposed cleanup standards are identical with the interim standards and require that remedial actions lower the average concentration of radium-226 in contaminated soil below 5 pCi/gm. In the rule, the 5 pCi/gm standard is to be measured at (1) any 5 cm thickness of soils or other materials on open land within 1 foot of the surface, or (2) any 15 cm thickness below 1 foot. Limits are also proposed on the radon decay product concentration and gamma radiation in occupied or occupiable buildings affected by tailings. The limits are the following:

- o The average annual indoor radon decay product concentration, including background, shall not exceed 0.015 working levels (WL).
- o Indoor gamma radiation, above background, shall not exceed 0.02 milliroentgen per hour.

A working level (WL) is a measure of the concentration of radioactivity in the air rather than how much radiation exposure a person receives. The concept of a WL grew out of a functional need to measure airborne radioactivity concentrations in mining operations and is defined by EPA as "any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts" (Ref. 10). One working level month (WLM) means the exposure to one WL for 170 hours, which is the number of working hours in a month based on a 40-hour working week.

Although EPA does not set a yearly allowable dose rate in the interim and proposed cleanup standards, EPA does observe as part of supplementary information to the standards that 0.02 mrad of gamma exposure per hour corresponds to 130 mrad/year to the average person. As noted by EPA, this assumes that the person spends 75 percent of his time in a structure where he receives the maximum hourly dose. (Note that 100 percent occupancy would correspond to 175 mrad/year.) EPA also notes that continuous exposure to 1 WL for an average person corresponds to 27 WLM in a year, and that one WLM is roughly equivalent to 0.5 rad to the lung (Ref. 10). This corresponds to roughly 200 mrad/year of alpha exposure to the lung for continuous occupancy of a building at 0.015 WL (about 150 mrad/year at 75 percent occupancy).

3. RECOMMENDATIONS OF THE NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS (NCRP)

The National Council on Radiation Protection and Measurements (NCRP) was originally formed in 1929 as the Advisory Committee on X-Ray and Radium Protection. Since that time, the NCRP has published numerous reports and recommendations on radiation protection and can be considered an authority in this country on radiation protection standards. During this time, the NCRP has worked closely with the International Commission on Radiation Protection (ICRP).

One of the more recent reports issued by NCRP is their Basic Radiation Protection Criteria Report No. 39, which was published on January 15, 1971 (Ref. 14). This report represents a culmination of NCRP review and reevaluation of the basic overall radiation protection criteria which were established by that organization in 1949 and amended in 1957.

NCRP Report No. 39 contains numerical recommendations on permissible levels of radiation dose equivalents received by workers, individuals, and populations.

These numerical recommendations are summarized below. In NCRP-39, recommendations are also made regarding permissible radiation exposures for emergency--including life saving--situations. These include the following:

<u>Maximum Permissible Dose Equivalents for Occupational Exposure</u>

Combined whole body:

o Prospective annual limit	5 rems in any one year
o Retrospective annual limit	10-15 rems in any one year
o Long-term accumulation	(N - 18) x 5 rems, where N = age in years
Skin	15 rems in any one year
Hands	75 rems in any one year
Forearms	30 rems in any one year
Other organs, tissues and organ systems	15 rems in any one year
Fertile women	0.5 rems in gestation period

<u>Dose Limits for the Public, or Occasionally Exposed Individuals</u>

Individual or occasional	0.5 rems in any one year
Students	0.1 rems in any one year

<u>Population Dose Limits</u>

Genetic	0.17 rems average per year
Somatic	0.17 rems average per year

In establishing the limits for individual members of the public, NCRP notes that experience in many large institutions has indicated that with a worker occupational limit of 5 rems/year, only a very small fraction of the potentially exposed workers would be actually expected to receive a yearly dose equivalent in excess of a tenth of 5 rems. NCRP asserts, therefore, that if an individual member of the public (or an occasionally exposed individual) were to be limited to 500 mrem/year, then the potential dose to an average individual would be expected to be much less--for example, at least a factor of 10 less.

In making this recommendation,* NCRP writes:

> ". . .the incremental radiation received by an individual is at most some four to five times the natural radiation, and is less than twice the existing background in some situations. With an intended limit of 0.5 rem per year for most, if not all, situations, the average incremental dose to population groups from radiation plants and installations would probably easily stay below 0.1 rem per year, comfortably within the limit that consideration of genetic effects sets for the whole populations."

In NCRP-39, NCRP further considers doses to populations. In this report, NCRP recommends that "dose equivalent to the gonads for the population of the United States as a whole from all sources of radiation other than natural radiation, and radiation from the healing arts shall not exceed a yearly average of 0.17 rem (170 mrem) per person." An identical recommendation is made as part of somatic considerations for potential doses to the critical organs (whole body). The recommended 170 mrem to the gonads was basically responsive to the 1956 recommendation of the National Academy of Science Committee on the Biological Effects of Atomic Radiation for an average maximum (per person) of 10 rems total exposure over the first 30 years of life. About half of this exposure was attributed to natural and medical-dental radiation. For manmade sources of radiation, therefore, a total exposure to the gonads of 5 rems over 30 years corresponds to a level of approximately 170 millirem/year.

The recommended limit for gonadal protection was then extended to the whole body as a practical simplification. In extending this limit to whole body (critical organs) considerations, NCRP states that they expect that the average population limit of 170 mrem (along with the dose limit of 500 mrem per year for any critical organ of an individual member of the public) will effectively control the actual population exposures to levels well below the given limit.

A more recent NCRP report, entitled "Review of the Current State of Radiation Protection Philosophy" (NCRP-43), was issued in January 1975 (Ref. 15). This document is essentially a position paper written in response to issues raised in reports published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (Ref. 16) and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR Committee) (Ref. 17). These reports treated the estimation of risks arising from exposure to ionizing radiation and essentially reached the same numerical results for radiation levels at which observations are available. However, there were differences in philosophy and divergent conclusions regarding the estimation of risk associated with low-level dose rate radiation.

---

*This recommendation is consistent with the earlier (1957) recommendation that the maximum dose in the general population be limited to 0.5 rem per year. In making this recommendation, NCRP held that no member of the public should be exposed at levels more than a factor of ten less than the recommended permissible annual occupational dose of 5 rems, as applied to the gonads, blood-forming organs, whole body, head, or trunk.

recommendations for radiation exposure is contained in their Report No. 1 issued in 1960 (Ref. 25). In these recommendations, FRC essentially adopted the NCRP recommendation that the dose to the whole body of the maximally exposed individual in the population should have a limit of 0.5 rem. In making this recommendation, FRC adopted the terminology of Radiation Protection Guides for exposure.

The FRC also considered population doses and a factor of 3 was recommended to allow for variations in radiation susceptibility of different groups in the general population to radiation effects (for example, the susceptibility of different age groups, sexes, and genetic backgrounds). Thus, FRC recommended an average yearly population exposure limit of 170 mrem (whole body), with a strong caveat that the limit be used with reason and judgment. As stated by the FRC..."it is noted that the use of the average figure, as a substitute for evidence concerning the dose to individuals, is permssible only when there is a probability of appreciable homogeneity concerning the distribution of the dose within the population included in the average." The figure of 170 mrem/year from somatic considerations coincided with the FRC's recommended average dose limit to the gonads of the population of 5 rems over 30 years.

In a later publication (FRC Report #5), FRC applies the recommended 170 mrem/year limit to the "critical segment" of the population receiving the highest dose from a given event resulting in environmental contamination (Ref. 26).

The functions of the FRC were later transferred to the EPA by the Reorganization Plan Number Three of 1970.

6. ENVIRONMENTAL PROTECTION AGENCY SOLID AND HAZARDOUS WASTE MANAGEMENT REGULATIONS

6.1 Management and Disposal of Nonradioactive Solid Waste

Regulations promulgated by the Environmental Protection Agency (EPA) for the disposal of nonradioactive solid waste are found in Subchapter I of Chapter 40 of the Code of Federal Regulations (40 CFR). As defined by EPA, "'solid waste' means any garbage, refuse, or sludge from a waste treatment plant, water supply treatment plant, or an air pollution control facility or other discarded material resulting from industrial commercial mining, and agricultural operations, and from community activities..." Regulations promulgated to date by EPA for the management and disposal of solid waste include:

- 40 CFR 240 Guidelines for the thermal processing of solid wastes.
- 40 CFR 241 Guidelines for the land disposal of solid wastes.
- 40 CFR 243 Guidelines for the storage and collection of residential, commercial, and institutional solid waste.
- 40 CFR 244 Solid waste management guidelines for beverage containers.
- 40 CFR 245 Promulgation resource recovery facilities guidelines.

- o 40 CFR 246 Source separation for materials recovery guidelines.
- o 40 CFR 247 Guidelines for precurement of products that contain recycled material.
- o 40 CFR 249 Public participation in solid waste management.
- o 40 CFR 254 Public notice of citizen suits.
- o 40 CFR 255 Identification of regions and agencies for solid waste management.
- o 40 CFR 256 Guidelines for development and implementation of state solid waste management plans.
- o 40 CFR 257 Criteria for classification of solid waste disposal facilities and practices.

Of special interest for the disposal of low-level waste are the regulations 40 CFR 241 (Guidelines for Landfill Disposal of Solid Waste) and 40 CFR 257 (Criteria for Classification of Solid Waste Disposal Facilities). The existing Part 241 regulation was originally promulgated on August 14, 1974 under the authority of the Solid Waste Disposal Act, as amended by the Resource Recovery Act of 1970 (Pub. L. 91-512). However, in March 1979, EPA published a Federal Register notice (44 FR 18138) proposing a new regulation, 40 CFR 241, which would entirely replace the existing regulation (Ref. 27). The revised Part 241 regulation, entitled "Guidelines for the Landfill Disposal of Solid Waste," is intended to give more explicit guidance regarding the location, design, construction, operation, and maintenance of solid waste landfill disposal facilities. Specific design features of a solid waste landfill are discussed for control of such potentially troublesome occurrences as leachate generation, gas generation, and run-off. Site monitoring is also discussed. The guidelines are meant to be a concise identification of recommendations. A more detailed description of the technical and economical aspects of recommended landfill practices can be found in the "Draft EIS on the Proposed Guidelines for the Landfill Disposal of Solid Waste" (March 1979) (Ref. 28).

The proposed guidelines stipulated in 40 CFR 241 are meant to closely interact with the recently promulgated EPA regulation 40 CFR 257, "Criteria for Classification of Solid Waste Disposal Facilities." These criteria were promulgated in September 1979 under the authority of Sections 1008(a)(3) and 4004(a) of the Solid Waste Disposal Act, as amended by the Resource Conservation Recovery Act of 1976 (RCRA) as well as Section 405(d) of the Clean Water Act, as amended (Ref. 29).

The criteria contains minimum criteria for the level of health and environmental protection that must be achieved by a land disposal facility. Those facilities that cannot meet the criteria are to be classified as "open dumps" for the purposes of RCRA. RCRA prohibits the practice of open dumping. The criteria also provides the criteria to be applied in the federal district courts in determining whether or not open dumping had occurred, in addition to

Based upon its analysis of the two reports and upon review of work available since the publishment of NCRP-39, the Council concluded that no change is required at that time in the conclusions set out in NCRP-39. In so concluding, the Council stated:

> "The NCRP continues to hold the view that risk estimates for radiogenic cancers at low doses and low dose rates derived on the basis of linear (proportional) extrapolation from the rising portions of the dose-incidence curves at high doses and high dose rates, as described and discussed in subsequent sections of this report, cannot be expected to provide realistic estimates of the actual risks from low level, low-LET radiations, and have such a high probability of overestimating the actual risk as to be of only marginal value, if any, for purposes of realistic risk-benefit evaluation.
>
> Such risk estimates by themselves do not consitute justification for urgent action to make numerical radiation protection standards more restrictive than they now are, assuming that the application of such standards adheres to the basic principle of lowest practicable levels of dose."

Also of interest is NCRP's Report No. 45, entitled "Natural Background Radiation in the United States" (November 15, 1975). This report presents a fairly comprehensive picture of the variations in exposures in the United States due to natural background radiation. Included are exposures from cosmic radiation and cosmic ray-produced radiation, direct inhalation and ingestion exposures from radionuclides found in the earth's crust, exposures due to fallout from nuclear weapon test programs, and exposures due to nuclear energy. Of interest is the great variability in natural radiation sources and potential exposures that can be received (Ref. 18).

4. RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP)

The International Commission on Radiological Protection (ICRP) is a body which reviews and analyzes potential health effects of ionizing radiation and publishes international recommendations for protection from ionizing radiation. Established in 1928 by the Second International Congress of Radiology, the ICRP was reorganized into its present structure in 1950. Over the years, the ICRP has issued a number of reports, recommendations, and guidance documents on radiation protection.

A recent and significant set of recommendations regarding basic radiation protection criteria were issued in 1977 as ICRP-26, which was issued based upon a review of new information which had emerged over the previous decade (Ref. 19). In this report, ICRP makes two major changes from previous recommendations as regards to (1) maximum recommended dose limits for individual organs, and (2) maximum limits for exposure to populations. Prior to discussing the recommendations contained in ICRP-26, however, it is instructive to briefly consider the development of the earlier recommendations.

The first recommendations of the ICRP were published in 1928, with additional reports following in 1931, 1934, and 1937. Following the 1950 reorganization, basic recommendations were issued in 1951, 1955, and 1959. The 1959 recommendations were published as ICRP-2 ("Report of Committee II on Permissible Dose for Internal Radiation"), and for 20 years served as a basic guide for the control of intakes of radionuclides into the body (Ref. 20). (The report was eventually superseded in 1979 by ICRP-30, discussed below.) These recommendations were subsequently subject to relatively minor revisions as newer data became available, and one such revision is ICRP-6, published in 1964 (Ref. 21).

In ICRP-6, the recommended maximum radiation level to individual members of the population at large is 0.5 rem per year to the gonads and blood-forming organs. In this report, the population at large is assumed to contain children. The recommended doses to other organs and tissues and to the extremities is one-tenth of the corresponding annual occupational dose. In the report, ICRP also recommends that the total genetic dose to the whole population from all sources in addition to natural background and medical exposures should not exceed 5 rem. The genetic dose to the population is taken as the dose received by each person from conception to the mean age of child bearing (30 years). A level of 5 rems per person over 30 years, therefore, corresponds to an average dose of 170 mrem/year.

ICRP-9, issued in 1965, was based upon a further review of ICRP's recommendations (Ref. 22). Substantive changes in recommended protection criteria for individuals and populations were relatively minor. Amendments to ICRP-9 were later issued in 1969 and 1971 (Ref. 19).

A summary of ICRP's recommended individual dose limits as of 1970 are included below (Ref. 23):

Summary of Dose Limits for Individuals

Organ or Tissue	Maximum Permissible Doses for Adults Exposed in the Course of Their Work	Dose Limits for Members of the Public
Gonads, red bone marrow	5 rems in a year	0.5 rems in a year
Skin, bone, thyroid	30 rems in a year	3 rems in a year*
Hands and forearms, feet and ankles	75 rems in a year	7.5 rems in a year
Other single organs	15 rems in a year	1.5 rems in a year

*1.5 rems in a year to the thyroid of children up to 16 years of age.

In ICRP-26, the Commission recommends a system of dose limitation, based upon the following criteria (Ref. 19):

"(a) No practice shall be adopted unless its introduction produces a positive net benefit;

(b) All exposures shall be kept as low as reasonably achievable, economic and social factors taken into account; and

(c) The dose equivalent shall not exceed the limits recommended for the appropriate circumstances by the Commission."

Based on these criteria, the Commission analyzes and makes recommendations on numerical dose-equivalent limits for workers (including occupational exposure of women of reproductive capacity and of pregnant women), for individual members of the public, and indirectly, exposure of populations.

In ICRP-26, the Commission retains the principal of accounting for the fact that different organs have different susceptabilities to radiation damage. However, rather than providing a list of maximum dose limits for individual organs, ICRP proposes a system whereby different organs would be assigned different weighting factors. Doses to each organ would be multiplied by the appropriate weighting factors and summed to obtain the equivalent whole body dose. The recommended occupational whole body dose limit is 5 rem/year. The recommended whole body dose limit for individual members of the public is 0.5 rem/year. The weighting factors (W_T) for the respective organs are:

gonads	0.25
breast	0.15
red bone marrow	0.12
lung	0.12
thyroid	0.03
bone surface	0.03
remainder	0.30

Thus, if only the breast were exposed, for example, an acceptable annual occupational exposure to the breast of a radiation worker would be 5 rem ÷ 0.15 = 33.3 rems. The Commission also recommends a value of W_T = 0.06 for each of the five organs or tissues receiving the highest dose equivalents. The exposure of all other remaining tissues can be neglected.

Similarly, the Commission recommends a total maximum whole body dose to individual members of the public of 0.5 rem/year. This corresponds to a fatal risk of an order of magnitude lower than that for occupational workers, or 10^{-6} to 10^{-5} per year. The weighting factors would again be utilized as discussed above.

ICRP also drops their previous recommended dose limit of 170 mrem to populations, stating that such a recommendation is not really needed to protect populations. The Commission believes that application of the 500 mrem/year dose equivalent whole body dose limit to individual members of the public would be likely to result in an average dose equivalent to the public of greater than an order of magnitude less (i.e., less than 50 mrem/year), provided that the practices exposing the public are few and cause little exposure outside the critical groups. Thus, the Commission believes that protection of an individual member of the public to a level of 0.5 rem/year (whole body), will ensure protection of populations.

Also of interest is the recently published ICRP-30, "Limits for Intakes of Radionuclides by Workers," a document that supersedes ICRP-2 (Ref. 24). In ICRP-30, annual limits for intakes (ALIs) of radionuclides are recommended. (ICRP defines an ALI as "the activity of a radionuclide which taken alone would irradiate a person, represented by Reference Man, to the limit set by the ICRP for each year of occupational exposure.") The system of dose limitation presented by the Commission in ICRP-30 takes account of all body tissues that are irradiated following intake of radioactive material rather than the former practice of only considering critical organs. The system is intended to ensure that the total risk from irradiation of any combination of organs does not exceed the equivalent whole body risk. The ALIs for some radionuclides are greater than others and are smaller than the equivalent ALIs that would be derived from the methodology in ICRP-2. These changes have principally resulted from improved knowledge of sensitivity of organs to radiation damage and of uptake and retention of radionuclides in bodily tissues, as well as the radioactive decay schemes of some radionuclides.

ICRP-30 also considers radiation risks. The recommended dose-equivalent risk for the lens of the eye is reduced from 0.3 Sv per year to 0.15 Sv per year. In addition, the document summarizes the Commission's review of additional epidemiological and radiobiological information available between May 1978 and March 1980. Aside from the recommendation regarding the eye lens, the Commission concludes that no change is called for from the recommendations in ICRP-26 regarding risk factors for stochastic effects or dose-effect relationships for nonstochastic effects basing the ICRP-26 dose-equivalent limits.

ICRP-30 is being issued in several parts, including supplements. Part 1, published in 1979, describes the dosimetric methods used and presents ALIs and metabolic data on twenty-one elements having isotopes that are significant in terms of radiation protection. A supplement to Part 1 contains further data regarding the radionuclides considered. Part 2 of ICRP-30, published in 1980, presents ALIs and metabolic data for an additional 30 elements. Similar data for 44 additional elements will be provided in Part 3.

5. RECOMMENDATIONS OF THE FEDERAL RADIATION COUNCIL (FRC)

The Federal Radiation Council (FRC) was formed in 1959 in the United States as a federal policy making group on health aspects due to exposure to ionizing radiation. In discharging its duties, the FRC has consulted such qualified organizations as the ICRP, NCRP, and National Academy of Science. FRC's basic providing guidelines (Section 405 of the Clean Water Act) for the utilization and disposal of waste water treatment plant sludge.

The purpose of the criteria is to determine whether there is "no reasonable probability of adverse effects on health or the environment." This determination would be made on a case-by-case basis, taking into account particular site-specific conditions at a particular facility. (The guidelines, on the other hand, are certified by EPA to represent sound solid waste management practices, but do not necessarily guarantee a site's compliance with the criteria. The guidelines are an informational resource which can assist state officials and site operators in determining the types of site practices which, if performed properly, would provide reasonable assurance that the criteria would be met. EPA notes that the criteria could also be met by employing a new innovative technology which is not discussed in the guidelines.) A guidance manual ("Draft Guidance Manual for the Classification of Solid Waste Disposal Facilities," November 1979). for use by state agencies and disposal site operators in determining compliance with the criteria has been issued by the EPA Office of Solid Waste staff (Ref. 30).

Criteria listed by EPA which if violated would "pose a reasonable probability of adverse effects on health or the environment" include criteria for:

- floodplains;
- endangered species;
- protection of surface water;
- protection of ground water;
- application to food-chain cropland;
- air quality; and
- safety (including control of gases, fires, bird hazard to aircraft and access).

Of particular interest are the criteria for protection of surface water and of ground water.

In the criteria, protection of surface water is carried out under the auspices of Sections 402, 404, and 208 of the Clean Water Act (CWA), as amended. Discharge of pollutants into the waters of the United States must conform to the requirements of the National Pollutant Discharge Elimination System (NPDES; Section 402 of the CWA). Discharge of dredged material or fill material must conform to the requirements of Section 404 of the CWA. Nonpoint source pollution of the waters of the United States must conform to an area-wide or state plan approved by the EPA Administrator (Section 208 of the CWA).

Protection of ground water is primarily based upon application of the National Primary Drinking Water (NPDW) regulation, 40 CFR 141 (see Section N.7). The criteria states that "a facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary or beyond an alternative boundary specified in accordance with paragraph b of this section." In this requirement, "contaminate" means to introduce a substance which would either exceed the allowable levels of contaminants listed in the NPDW Standard, or increase the concentration of the substance in the ground water where the existing levels of that substance already exceed the allowable levels. The definition of an underground drinking water source is:

"(i) An aquifer supplying drinking water for human consumption;

(ii) An aquifer in which the ground water contains less than 10,000 mg/1 total dissolved solids; or

(iii) An aquifer designated as such by the (EPA) administra or or a state."

A solid waste boundary means "the outermost perimeter of the solid waste (projected in the horizontal plane) as it would exist at completion of the disposal activity." Finally, Paragraph b establishes means by which a state with a solid waste management plan approved by the EPA administrator may specify an alternative boundary for application of the ground-water criteria other than the solid waste boundary.

The criteria would appear to essentially provide for no releases from a facility when existing contaminant levels exceed the specified limits. This implies that an aquifer that is contaminated either naturally or artificially (by man) could be protected to a greater degree than one that is uncontaminated. The criteria are also unclear as to their applicability when the aquifer in question is not an underground drinking water source. The ground-water criteria are similar to those proposed by EPA in December 1978 for disposal of hazardous wastes. (See discussion below of EPA's hazardous waste regulations.)

The criteria and the use of the criteria by EPA are related to the characteristics of the waste to be disposed. Annually, hundreds of millions of tons of solid and hazardous wastes are produced, not counting mining wastes. There are over 18,500 solid waste disposal sites in the U.S. (Ref. 31). The characteristics of the waste streams are very hard to specify. Much of the waste is in a liquid or in a semisolid form, or is otherwise easily compressible. Much of the contaminant materials are essentially nonbiodegradable. Inorganic toxic elements such as arsenic, cadmium, chromium, lead, mercury, and selenium have essentially infinite half-lives. Previous improper disposal practices have contaminated ground water on a local basis in many parts of the nation and on a regional basis in some heavily populated and industrialized areas, precluding its use as drinking water.

The great volume of the waste material to be disposed has dictated certain practical limitations in alternative methods for disposal of the waste--that is, the key practical disposal method for most of the waste is by some variation of landfill operations. This fact, coupled with the very great difficulty in predicting the impacts of large volumes of diverse, long-lasting difficult-to-characterize waste material, has led to use of "impermeable" liners on the bottom of the landfills. The aim is essentially "zero release" from these facilities. The facilities would be designed to collect, remove, and treat any leachate produced by infiltrating precipitation prior to discharge to the environment. However, the release of collected and treated leachate would not constitute "zero release" and the system implies a more or less continual maintenance requirement which someone will have to pay for once the site license has been terminated.

EPA is also considering expanding the list of maximum contaminant levels used in the criteria to include those levels published in the National Secondary Drinking Water Regulations (40 CFR 143). A Federal Register notice (44 FR 53465) announcing the proposed amendment to the criteria was issued by EPA in September 1979 (Ref. 37). The proposed amendment would add maximum permissible levels for eleven contaminants, including chloride, color, foaming agents, iron, manganese, odor, pH, sulfate, total dissolved solids, and zinc. These additions are intended to protect ground water from discoloration, odor, and taste-causing contaminants.

6.2 Management and Disposal of Hazardous Waste

The authority of the EPA to promulgate regulations to protect human health and the environment is provided under the authority of the Resource Conservation and Recovery Act of 1976, as amended--an act which significantly amended the earlier Solid Waste Disposal Act.

A sweeping set of procedural, administrative, and technical regulations for the management and disposal of hazardous waste was proposed by EPA as 40 CFR 250 on December 18, 1978 (Ref. 33). Over a thousand comments on the proposed rule from the public were subsequently received by EPA. Since the December 1978 Notice of Proposed Rulemaking, the EPA has completely reorganized the proposed regulation into a number of parts of Title 40 and are promulgating separate parts at different times. A listing of the principal parts of 40 CFR applicable to hazardous waste management are provided below (Ref. 34).

- 40 CFR 260 — Hazardous Waste Management: General.
- 40 CFR 261 — Hazardous Waste Management System: Identification and Listing of Hazardous Waste.
- 40 CFR 262 — Standards for Generators of Hazardous Waste.
- 40 CFR 263 — Standards for Transporters of Hazardous Waste.
- 40 CFR 264 — Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.
- 40 CFR 265 — Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.

- o 40 CFR 122 EPA Administered Permit Program: The National Pollutant Discharge Elimination System; the Hazardous Waste Permit Program; and the Underground Injection Control Program.
- o 40 CFR 123 State Program Requirements.
- o 40 CFR 124 Procedures for Decisionmaking.
- o 40 CFR 125 Criteria and Standards for the National Pollutant Discharge Elimination System.

Parts of 40 CFR 260 were originally promulgated on February 26, 1980 (Ref. 35), concurrent with promulgation of Parts 262 and 263. However, certain provisions of Parts 260, 262, and 263 were amended on May 19, 1980 to reflect some additional refinements as well as changes due to the publication of Parts 261, 264, and 265. Parts 261, 264, and 265 were also published on May 19, as well as extensive amendments to Parts 122, 123, 124, and 125 (Ref. 34).

The following is a brief discussion of EPA's requirements for notification of hazardous waste activities, as well as a discussion of each separate part:

Preliminary notification of hazardous waste activity. A notification form (and procedures for filling it out) for persons engaged in hazardous waste activities was issued by EPA and noticed in the Federal Register on February 26, 1980 (45 FR 12746). As required by Section 3010 of RCRA and codified by the notification form, each person who generates or transports hazardous waste, or who owns or operates a facility for the treatment, storage, or disposal of hazardous waste must notify EPA of their activities within 90 days of the publication of the Federal Register notice. Alternatively, notification is to be given to those states having authorized hazardous waste permit programs (see 40 CFR 123). Specific requirements for generators, transporters, and owner/operators of treatment, storage, or disposal facilities are provided in Parts 262 through 265.

Those who fail to comply with the notification requirement may be compelled by EPA to close operations. In addition, owner/operators of treatment, storage, or disposal facilities that do not comply with the notification requirements may become ineligible for interim status as provided in Part 265.

The function of the notification form is to identify all those who are currently engaged in hazardous waste activities. This may entail as many as 400,000 persons, businesses, and federal agencies. Respondees to the notification form will be issued a 12-digit identification number to be used on shipping manifests and other reporting forms required under Parts 262 through 265. This will facilitate EPA's use of a computer-based system for monitoring hazardous waste activities in the country.

40 CFR 260. The intent of 40 CFR 260 is to consolidate in one part several provisions which are generally applicable to Parts 261 through 265. Provisions contained in Part 260 include:

- o Rules concerning the designation and handling of confidential information;
- o Rules concerning grammatical construction;
- o Definitions of key word and phrases;
- o Rules concerning EPA procedures to act on petitions for rulemaking and alternative analytical test methods; and
- o A "road map" to the hazardous waste regulations providing general guidance regarding the most important provisions of the regulations.

40 CFR 261. This regulation (May 19, 1980; 45 FR 33084) identifies the criteria for and characteristics of hazardous wastes as well as provides lists of several wastes which must be managed as hazardous wastes. Certain portions of 40 CFR 261--particularly administrative and procedural portions--are promulgated as final rules. Other portions, including the lists of hazardous wastes, the criteria for listing hazardous waste, and the definitions of solid waste and domestic sewage, are being issued as "interim final" regulations. Public comment on the interim final regulations is encouraged prior to their being issued by EPA as final regulations.

According to the criteria, a waste stream is hazardous if it exhibits certain characteristics, is fatal in low doses to humans or laboratory animals, contributes to illness, or contains certain listed toxic constituents. Characteristics of hazardous wastes include ignitabilty, corrosivity, reactivity, or extraction procedure (EP) toxicity. (According to the EP toxicity procedure, a waste stream is considered hazardous if a prescribed test of the waste produces an extract of chemicals 100 times greater than the maximum levels listed in the National Primary Drinking Water (NPDW) regulation, 40 CFR 141.) The lists of hazardous waste streams currently include 85 waste streams from certain industrial processes as hazardous. More waste streams are scheduled to be listed in the summer and fall of this year. In addition, approximately 400 chemicals are listed which are considered to be hazardous if not disposed properly.

In the Part 261 regulation, EPA doesn't generally classify hazardous waste according to the degree of the hazard. All wastes that fall under the criteria are essentially disposed on an equal basis. Special procedures are required in other parts, however, depending on chemical characteristics such as compatability or physical characteristics such as liquidity.

Certain wastes are specifically excluded from consideration as hazardous wastes. These include domestic sewage, industrial point source waste water discharges, irrigation return flows, material subject to regulation by NRC, household wastes, agricultural wastes, ash from burning fossil fuels, drilling fluids, and materials subject to in situ mining techniques but not removed from the ground. In addition, persons generating less than 1000 kg of hazardous wastes per month are exempt from the promulgated requirements. (This criterion of 1000 kg/month is 10 times greater than the limit in the 1978 proposed rule.)

40 CFR 262. Part 262 provides requirements for generators of hazardous waste. The main portions of the regulation were promulgated on February 26, 1980 (45 FR 12722) and revised as of May 19, 1980 (45 FR 33140) to incorporate certain administrative and technical refinements. The regulation requires that a person determine whether or not he generates a hazardous waste under the requirements of Part 261. If so, and if he stores this hazardous waste onsite for a period greater than 90 days, he is then considered to operate a waste storage facility that must comply with the detailed requirements of Parts 122, 264, and 265. If he stores the hazardous waste for less than 90 days and complies with certain other requirements such as containing and labeling wastes, he is considered to be a waste generator and is subject to other requirements.

The heart of Part 262 is the hazardous waste manifest system. This system is meant to track the generation, transport, and disposal of hazardous waste "from cradle to grave," and therefore greatly reduce such improper waste disposal practices as midnight dumping. Under the regulation, generators are required to identify themselves and to describe the waste (type, weight, and volume) on the manifest, which must accompany the waste shipment to the disposal facility. The disposal facility to which the wastes will be sent must be indicated on the manifest, as well as at least one alternative facility. A certification requirement is also included. Other requirements in the regulation include requirements for packaging, labeling, marking, and placarding in compliance with DOT requirements in 49 CFR Parts 172, 173, 178, and 179.

Also of interest are the recordkeeping and reporting requirements. After receiving and disposing of a waste shipment, an operator of a waste disposal facility must sign the accompanying manifest document and return a copy of it to the waste generator. If the waste generator does not receive the returned manifest document within 35 days after he has shipped the waste, he must locate the waste shipment. Failing to locate the waste shipment, the waste generator must submit an exception report to the EPA.

Other requirements on the waste generator include those for recordkeeping and for annual reporting to the EPA.

40 CFR 263. These regulations, prescribing standards for the transporters of hazardous waste, were originally promulgated on February 26, 1980 (45 FR 12737). Minor administrative amendments were noticed in the Federal Register on May 19, 1980 (45 FR 33150).

Under the regulation, a transporter must not transport hazardous waste material without applying for and receiving an identification number from the EPA. The transporter may not accept a hazardous waste shipment from a generator without it being accompanied by a manifest. The transporter must then ensure that the manifest accompanies the hazardous waste and deliver the manifest to the disposal facility along with the waste shipment. Less restrictive requirements apply to the bulk shipments of waste transported by rail or water. Also included in the regulation are recordkeeping requirements as well as requirements on the transporters to undertake immediate cleanup actions on any waste spills during transport.

40 CFR 264 and 265. Parts 264 and 265 are very closely related and were promulgated by EPA in recognition of the many hundreds of hazardous waste facilities already existing. Both regulations apply to owners and operators of hazardous waste treatment, storage, and disposal facilities. The Part 265 regulations are a less restrictive (abbreviated) set of regulations than the Part 264 regulations which will eventually apply to those owners/operators which qualify for "interim" status under the regulation. To qualify for interim status, an owner/operator must:

1. Have been treating, storing, or disposing of hazardous waste prior to October 21, 1976, or have had a hazardous waste facility under construction before that date;

2. Notify EPA in compliance with requirements promulgated pursuant to Section 3010 of the Solid Waste Disposal Act (see the earlier discussion on notification of hazardous waste activity); and

3. Apply for a permit pursuant to 40 CFR 122.

Assuming that an owner/operator complies with these requirements, he may then operate under Part 265 while EPA evaluates his permit. EPA expects that, due to the sheer number of applicants, several years may elapse prior to their issuing a permit to some owner/operators that have been awarded interim status. When a permit is eventually issued to such a facility, the permit will be issued based on the Part 264 requirements.

New facilities must, of course, comply with the more restrictive Part 264 requirements. As discussed below, the Part 264 regulations currently cover only administrative and procedural matters. Existing facilities which do not qualify for interim status under the above rules must stop operations at the storage/treatment/disposal facility pending issuance of a permit under the Part 264 requirements.

In the proposed regulations issued in October 1978, EPA specified a set of detailed prescriptive technical requirements for operation of a storage, treatment, or disposal facility. However, in the May 19 interim final regulations, EPA has adopted a much more general performance-objective approach. As stated in the May 19 Federal Register notice (Ref. 34, 45 FR 33156), EPA believes that it will take "several years to promulgate detailed national technical standards for some types of facilities (for example, the design requirements for landfills)." Therefore, EPA is promulgating its hazardous waste standards under Parts 264 and 265 in three phases. Phase I corresponds to the regulations issued on May 19. Phase II requirements are expected later this year and will contain more detailed technical requirements. Phase III will involve a further refinement of the Phase I and Phase II standards based upon additional study and operational experience.

The Phase I regulations form a relatively complete set of administrative and procedural interim status standards as well as an abbreviated set of interim status technical standards (Part 265). On the other hand, the general status regulations (Part 264) cover only administrative and procedural requirements. The main subparts of the two parts include:

Part 264	Part 265
A. General	A. General
B. General Facility Standards	B. General Facility Standards
C. Preparedness and Prevention	C. Preparedness and Prevention
D. Contingency Plan and Emergency Procedures	D. Contingency Plan and Emergency Procedures
E. Manifest System, Recordkeeping, and Reporting	E. Manifest System, Recordkeeping, and Reporting
	F. Ground-water Monitoring
	G. Closure and Postclosure
	H. Financial Requirements
	I. Use and Management of Containers
	J. Tanks
	K. Surface Impoundments
	L. Waste Piles
	M. Land Treatment
	N. Landfills
	O. Incinerators
	P. Chemical, Physical, and Biological Treatment
	Q. Underground Injection

The Phase I (March 19) regulations do not contain any specific standards regarding protection of ground water. These are scheduled by EPA to be promulgated as part of the Phase II regulations. However, the Part 265 regulations do require that all hazardous waste disposal facilities or surface impoundments institute a ground-water monitoring program which includes at least one monitoring well up-gradient and three wells down-gradient of the facility. Other technical requirements include those for control of precipitation or other surface run-on to or run-off from active portions of a disposal facility. Also included are requirements for security, daily inspections by the site owner/operator, and waste liquids, as well as special requirements for ignitable, reactive, or incompatible wastes.

Of special interest are the Phase I regulations for closure, financing, and institutional controls. Under the regulations, every owner/operator of a hazardous waste facility must submit a site closure plan (Part 265, Subpart G). This plan is intended to be resubmitted by the owner/operator and reviewed by the EPA at five-year intervals. Also included as a part of the closure regulations is a requirement that each owner/operator submit an estimate (to be updated annually) of the projected closure costs. There are, however, no requirements for acceptable funding mechanisms to ensure that sufficient capital will be available for closure and postclosure maintenance and monitoring of a disposal facility. As part of the original December 1978 proposed rule, EPA proposed that an owner/operator make a cash deposit for the entire amount of the closure cost estimate into a closure trust fund. Based on comments received, EPA decided to repropose the financial requirements for Parts 264 and 265 (see 45 FR 33260; May 19, 1980). The new proposed rule would allow greater flexibility in meeting the financial requirement. Other options for funding are considered acceptable (i.e., use of surety bonds, letters of credit, individual company financial worth), and payments may be made over a 20-year period. The proposed rule would also require liability insurance.

Part 265 requires that after closure, the owner/operator maintain a disposal site for 30 years. More than or less than 30 years may also be acceptable depending upon site-specific conditions. After the owner/operator has been relieved of responsibility of the site, it is not clear, however, to whom the title to the site passes.

40 CFR 122, 123, 124, and 125. NRC issues licenses for control of radioactive materials principally under one act--the Atomic Energy Act of 1954. EPA, however, issues permits as part of programs established by a number of acts. These include:

- The Hazardous Waste Management Program under the Resource Conservation and Recovery Act (RCRA);
- The Underground Injection Control (UIC) program under the Safe Drinking Water Act (SDWA);
- The National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act (CWA);
- The state dredge or fill programs under Section 404 of the CWA (commonly termed the "State 404 Programs"); and
- The Prevention of Significant Deterioration (PSD) program under the Clean Air Act (CAA).

The intent, therefore, of the extensive revisions to Parts 122 through 124 (45 FR 33290) is to consolidate the program-permitting requirements for the RCRA and UIC programs with those already established for the NPDES program. Also consolidated are the permit issuance procedures for the PSD permits under the CAA with those permits issued for the RCRA, UIC, and NPDES programs. Newly established are requirements for state programs under the RCRA, UIC, and Section 404 programs.

Summaries of each of the revised EPA regulations are as follows:

- Part 122 ("EPA Administered Permit Programs") establishes definitions and general permitting requirements for RCRA, UIC, and NPDES programs administered by EPA. These requirements include applicability (that is, who must apply for a permit); contents of permit applications; mandatory permit conditions; and procedures for revision, reissuance, or termination of permits. Certain requirements applicable to state programs are also presented.

- Part 123 ("State Program Requirements") establishes requirements and procedures for state programs for the management and control of hazardous material, as well as procedures for EPA approval, revision, and potential withdrawal of a state program. EPA programs which may be transferred to approved state control include the RCRA hazardous waste program, UIC program, NPDES program, and the Section 404 programs for control of discharge or dredged or fill materials into the waters of the United States. Included in the Part 123 requirements are requirements for public participation in the issuance of permits.

- Part 124 ("Procedures for Decisionmaking") establishes EPA procedures for actions on permit applications made as part of the RCRA hazardous waste, UIC, PSD, and NPDES programs. Included are procedures for public participation, consolidated review and issuance of two or more permits to the same facility or for the same activity, and for appealing EPA decisions.

- Part 125 contains criteria and standards for the National Pollutant Discharge Elimination System. On May 19, some minor revisions and technical amendments were promulgated (45 FR 33512) principally to correct certain cross references to Parts 122, 123, and 124. As noted above, these parts were extensively revised under the May 19 promulgated rule.

Consolidated permit application forms were also published on May 19 in the Federal Register (45 FR 33516).

7. 40 CFR 141: NATIONAL PRIMARY DRINKING WATER REGULATION

The National Primary Drinking Water (NPDW) regulation was promulgated by the Environmental Protection Agency (EPA) pursuant to Sections 1412, 1414, 1415, and 1450 of the Public Health Service Act, as amended by the Safe Drinking Water Act (Pub. L. 93-523). The regulations cover allowable chemical (40 FR 59566, Dec. 24, 1975) and radiological (41 FR 28402, July 9, 1976) contamination in a "public water system." A guide book on the regulation has been published, entitled "National Interim Primary Drinking Water Regulations" (Ref. 36).

In the regulation, a public water system is defined as a "system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves 25 individuals daily at least 60 days out of the year." The definition further distinguishes between a "community water system" or a "noncommunity water system," where:

1. A community water system is a "public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents"; and

2. A noncommunity water system is "a public water system that is not a community water system."

In the regulation, maximum nonradioactive contaminant levels are stipulated for certain inorganic chemicals, organic chemicals, turbidity, and microbiological activity.

Requirements for radioactive elements in ground water include the following:

Maximum containment levels for radium-226, radium-228, and gross alpha particles:

- Combined radium-226 and radium-228: 5 pCi/l.
- Gross alpha particle activity (including radium-226 but excluding radon and uranium): 15 pCi/l.

In addition, the regulation states that the concentration of beta particles and photon radioactivity from man-made radionuclides in drinking water should not produce an annual dose equivalent to the total body or to any internal organ greater than 4 millirem/year. If two or more (man-made) radionuclides are present, the sum of the annual dose equivalent to the total body or to any organ shall not exceed 4 millirem/year.

The regulation also contains requirements for water sampling and monitoring, analytical techniques, recordkeeping, and reporting. If the concentrations of the contamination in a public water supply exceed those in the standard, the water supplier is required to notify billing customers. This notification is to take the form of a notice included with the bill as well as publication of the notice in a local newspaper(s). A copy of the notice is to be provided to radio and television stations servicing the area. No enforcement provisions are contained in the regulation in the event that the containment levels are exceeded or if the water supplier fails to carry out the provision in the regulation as regards to monitoring, recordkeeping, reporting, or notification of excessive contamination levels.

The regulation makes no specific mention of alpha-emitting transuranic radionuclides.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Advance Notice of Proposed Rulemaking on 10 CFR Part 20, Standards for Protection Against Radiation, Federal Register, 45 FR 18023, March 20, 1980.

2. U.S. Nuclear Regulatory Commission, Proposed Rule, 10 CFR 20, Standards for Protection Against Radiation: Environmental Radiation Protection Standards for Nuclear Power Operation, Federal Register, 45 FR 26072, April 17, 1980.

3. U.S. Nuclear Regulatory Commission, Final Rule: 10 CFR 20, Standards for Protection Against Radiation; Burial of Small Quantities of Radionuclides, Federal Register 45 FR 71761, October 30, 1980.

4. U.S. Nuclear Regulatory Commission, Final Rule: 10 CFR 20, Standards for Protection Against Radiation; Biomedical Waste Disposal, Federal Register, 46 FR 16230, March 11, 1981.

5. U.S. Nuclear Regulatory Commission, Final Environmental Statement Concerning Proposed Rulemaking Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as Practicable' For Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents, WASH-1258, July 1973.

6. IRG, Report to the President by the Interagency Review Group (IRG) on Nuclear Waste Management, TID-29442, March 1979.

7. EPA, Proposed Criteria for Radioactive Waste: Recommendations for Federal Radiation Guidance, Federal Register, 43 FR 53262, November 15, 1978.

8. EPA, Final Environmental Statement: Environmental Radiation Protection Requirements for Normal Operations of Activities in the Uranium Fuel Cycle, EPA 520/4-76-016, November 1976.

9. EPA, Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the Environment, Federal Register, 42 FR 60956, November 30, 1977.

10. EPA, Interim Cleanup Standards for Inactive Uranium Processing Sites, Federal Register, 45 FR 27366, April 22, 1980.

11. EPA, Proposed Cleanup Standards for Inactive Uranium Processing Sites; Invitation for Comment, Federal Register, 45 FR 22370, April 22, 1980.

12. EPA, Proposed Disposal Standards for Inactive Uranium Processing Sites; Proposed Rule and Extension of Comment Period, Federal Register, 46 FR 2556, January 9, 1981.

13. EPA, Draft Environmental Impact Statement on Proposed Disposal Standards for Inactive Uranium Processing Sites, EPA 520/4-80-011, 1981.

14. NCRP, Basic Radiation Protection Criteria, NCRP Report No. 39, National Council on Radiation Protection and Measurements, Washington, D.C., January 1971.

15. NCRP, Review of the Current State of Radiation Protection Philosophy, NCRP Report No. 43, National Council on Radiation Protection and Measurements, Washington, D.C., January 1975.

16. United Nations Scientific Committee on the Effects of Atomic Radiation, Ionizing Radiation: Levels and Effects, United Nations, New York, 1972.

17. National Academy of Sciences--National Research Council, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, National Academy of Sciences--National Research Council, Washington, D.C., 1972.

18. NCRP, Natural Background Radiation in the United States, NCRP Report No. 45, National Council on Radiation Protection and Measurements, Washington, D.C., November 1975.

19. ICRP, Recommendations of the International Commission on Radiological Protection, ICRP-26, International Commission on Radiological Protection, Pergamon Press, Oxford, 1977.

20. ICRP, Recommendations of the International Commission on Radiological Protection: Report of Committee II on Permissible Dose for Internal Radiation, (1959), ICRP-2, International Commission on Radiological Protection, Pergamon Press, Oxford, 1960.

21. ICRP, Recommendations of the International Commission on Radiological Protection (as amended 1959 and revised 1962), ICRP-6, International Commission on Radiological Protection, Pergamon Press, Oxford, 1964.

22. ICRP, Recommendations of the International Commission on Radiological Protection (adopted September 17, 1965), ICRP-9, International Commission on Radiological Protection, Pergamon Press, Oxford, 1966.

23. ICRP, Protection Against Ionizing Radiation From External Sources, A Report of ICRP Committee 3, ICRP-15, International Commission on Radiological Protection, Pergamon Press, Oxford, 1970.

24. ICRP, Limits For Intakes of Radionuclides by Workers, ICRP-30, International Commission on Radiological Protection, Pergamon Press, Oxford, Part 1: 1979, Part 2: 1980.

25. Federal Radiation Council, Background Material For The Development of Radiation Protection Standards, FRC Report No. 1, Washington, DC, 1960.

26. Federal Radiation Council, Background Material For the Development of Radiation Protection Standards, FRC Report Report No. 5, Washington, DC, 1964.

27. EPA, Proposed Guidelines, 40 CFR Part 241: Guidelines For the Land Fill Disposal of Solid Waste, Federal Register, 44 FR 18138, March 26, 1979.

28. EPA, Draft Environmental Impact Statement on the Proposed Guidelines For the Land Fill Disposal of Solid Waste, EPA Office of Solid Waste, March 1979.

29. EPA, Final Rule and Interim Rule: Criteria For Classification of Solid Waste Disposal Facilities and Practices, Federal Register, 44 FR 53438, September 13, 1979.

30. EPA, Draft Guidance Manual For the Classification of Solid Waste Disposal Facilities, EPA Office of Solid Waste, November 1979.

31. EPA, Solid Waste Facts: A Statistical Handbook, SW 694, October 1979.

32. EPA, Proposed Rule, 40 CFR 257: Criteria for Classification of Solid Waste Disposal Facilities and Practices Amendment, Federal Register, 44 CFR 53465, September 13, 1979.

33. EPA, Proposed Rule, 40 CFR 250: Hazardous Waste Guidelines and Regulations, Federal Register, 45 CFR 58946, December 18, 1978.

34. EPA, Hazardous Waste and Consolidated Permit Regulations, Federal Register, 45 FR 33066, 33587, May 19, 1960.

35. EPA, Final Rule, 40 CFR 260, 262 and 263: Hazardous Waste Management System, Federal Register, 45 FR 12723, February 26, 1980.

36. EPA, National Interim Primary Drinking Water Regulations, EPA-570/9-76-003, 1976.

Appendix O

(Reserved for final EIS)

Appendix P

(Reserved for final EIS)

Appendix Q

CALCULATION OF PREOPERATIONAL, OPERATIONAL, CLOSURE AND INSTITUTIONAL CONTROL COSTS

1. INTRODUCTION

This appendix presents a summary of the assumptions and calculational procedures used in this environmental impact statement to determine costs for siting, designing, constructing, operating, and closing a reference radioactive waste disposal facility, as well as costs for 100 years of active institutional control (the terms institutional control and long-term care are used synonymously). The costs are calculated in three segments:

1. Capital Costs, which include costs associated with siting, designing, licensing and initial construction of the facility.

2. Operational Costs, which include costs associated with receipt and disposal of waste, as well as construction of disposal cells.

3. Postoperational Costs, which include costs for (a) facility closure, and (b) institutional control by the site owner.

Included in the calculations are costs associated with acquisition by the licensee of surety bonds, letters of credit, or other financial instruments which are used to provide assurance to the site owner that funding for closure and institutional control will be available. For the purposes of this appendix, it is assumed that the licensee acquires a surety bond sufficient to cover the entire facility closure costs. Funding for closure and institutional control is assumed to be provided by sinking funds into which money is periodically placed after being collected as a surcharge on waste received at the disposal facility.

In this appendix, capital costs are discussed in Section 2.0, operational costs are discussed in Section 3.0, and postoperational costs are discussed in Section 4.0. In each section, a sample calculation is performed using the reference facility described in Appendix E as an example. Following these sections is Section 5.0, which analyzes some financial aspects connected with closure and institutional control. Section 6.0 then summarizes the example calculations performed in the previous three sections and provides an example calculation of a total unit disposal cost (\$ per m^3 of waste). (The total unit disposal cost is that charge sufficient to amortize the capital investment, pay all operating expenses, earn a specified rate of return on equity and establish a fund of sufficient size to pay for all site closure and institutional control expenses.) The unit disposal cost is derived by multiplying a set of factors by each of the three cost components (capital, operational and post-operational costs).

2. CAPITAL COSTS

Capital costs include all costs required to site, design, license, and construct a disposal facility; and include direct costs, indirect costs, and an annual fixed capital charge. Direct costs are costs which can be specifically assigned to particular tasks or actions, such as construction of a building or installation of a particular piece of equipment. Indirect costs are calculated as a percentage of the direct costs and are costs incurred during siting, licensing, and construction operations which cannot be specifically allocated to particular tasks or actions. The annual fixed capital charge is a fixed charge that occurs during the operating life of the facility, but is calculated as a percentage of the capital costs. It represents that portion of the total costs which are required during the (20 year) operating life to recover capital and interest expenses and to earn a specified return on a firm's equity.

2.1 Direct Capital Costs

Direct capital costs include the material, labor, overhead and necessary site improvements required to site, license and construct the facility. In this appendix, direct capital costs are assumed to include costs for:

- Site selection;
- Environmental impact studies;
- Administrative support;
- Licenses and permits;
- Site improvements (e.g., roads, fences, lights, etc.);
- Buildings and structures; and
- Engineering and design costs.

In the analysis, the required direct labor costs are assumed to be included as part of construction operations. For the purposes of this environmental impact statement, costs for site selection, environmental impact studies, and licenses and permits are assumed to be constant for all the alternatives considered. Adminstrative and legal costs are also assumed to be constant. The costs for buildings, structures, and other site construction activities, however, are a variable depending upon the alternatives considered.

In this appendix, equipment used to construct disposal cells (e.g., disposal trenches), to dispose of received wastes, and to carry out support activities are not included as part of the capital costs but are included as equipment leasing charges through the operational life of the facility. At an actual disposal facility, some equipment would undoubtedly be purchased--possibly second hand--and some would probably be leased. Assuming that equipment is purchased would require a number of additional assumptions regarding purchase costs, finance charges, insurance, depreciation, equipment operating life before replacement, salvage value, and so forth. As a simplification, therefore, all equipment is assumed to be leased. This assumption is maintained consistently through the alternatives considered in this environmental impact statement for facility design and operation.

For the reference facility presented in Appendix E, the following items are included as direct capital costs, in 1980 dollars:

Capital Outlay	1980 $ (X 1000)
1. Site selection	$ 500
2. Environmental impact studies	600
3. NRC licensing fees	325
4. Other licenses and permits	250
5. Land acquisition (200 acres @ $1200/acre)	240
6. Corporate administration	1,625.25
7. Construction administration	450.45
8. Legal fees	1,000
9. Road construction	200
10. Initial land preparation (40 acres @ $1145/acre)	45.8
11. Office and other miscellaneous light equipment	400
12. Building construction	1,173.25
13. Utilities and supplies during construction	175
14. Peripheral systems (fencing, lighting, utilities installation, telephone, etc.)	300
15. Engineering and design (10% of items 9, 12, and 14)	167.3
	$ 7,452.

The costs for items 1 through 4 above are held constant throughout the alternatives considered in this environmental impact statement. The costs for the other items, however, may vary depending upon the alternatives considered.

Building costs, which include the costs of labor required for construction, may be estimated as follows:

Building	1980$
Administration	$ 235,400
Health physics/security	387,500
Warehouse	126,500
Garage	113,000
Waste activities	302,250
Storage shed	8,600
	$ 1,173,250

Building costs are assumed to vary depending upon the complexity of the activities taking place within the particular building. For example, costs ranged from $108/m^2$ ($10/ft^2) for the storage shed to $538/m^2 ($50/ft^2) for the waste activities building, with an average building cost of $388/m^2 ($36/ft^2). A description of the function(s) of each building is provided in Appendix E.

Engineering and design costs are assumed to be 10% of the costs for road and building construction and installation of peripheral systems (fencing, lighting, utilities, monitoring wells, telephone connections, etc.). These costs include the costs associated with consulting, quality control, and inspection fees.

Estimated costs for corporate administration during facility siting, design, licensing, and construction are assumed to persist for 5 years and are broken down in Table Q.1. During initial construction of the facility, which is assumed to last one year, additional manpower is required to oversee site activities, to coordinate contracts, and to arrange for waste shipment customers. All personnel charges are increased from the basic rates by addition of a 10% fringe charge. A 50% overhead is then calculated from the combined base and fringe charges. Also shown in Table 1 are the legal fees during facility siting, licensing, and construction. These are assumed to average approximately $200,000 per year for each of the five years.

2.2 Indirect Capital Costs

Indirect capital costs are expenses of a general nature which apply to the overall project of siting, licensing, designing and constructing the disposal facility, and are calculated as a percentage of the direct capital costs. For the purposes of this environmental impact statement, the indirect costs are estimated as follows:

Item	Percentage of Direct Costs
Interest during construction	33
Contingency	30
Other Costs	10
	73 %

Interest during construction charges include the sum of interest charges for capital expenditures. It covers the net cost of funds utilized to finance the siting, design, and construction of the facility. Interest charges are a function of the amount of expenditures, the time period for which funds are borrowed, and the interest rate. Interest charges are included in the indirect capital costs even if the money used during siting and construction activities is from the company's own funds. (It is a "return" that could have been realized if that money were invested during the operational lifetime of the facility.) For this appendix, the interest on construction was calculated at 6-month intervals assuming a 15% interest rate over a period of five years. In addition, the rate that funds are expended is assumed to increase during the five years prior to facility operation--i.e., $2.4 million is spent during the first two years, an additional $1.5 million is spent over the next two years, and the remainder over the last year.

Contingency costs cover any additional (unplanned for) costs that may arise during siting, licensing, and constructing the disposal facility. An example is the possible need to acquire additional hydrogeologic data regarding the proposed disposal facility. Other costs cover miscellaneous overhead expenses during the preoperational phase such as insurance, sales tax on purchased equipment and material, and so forth.

Table Q.1 Administrative Costs During Siting, Licensing, and Construction

			Costs ($x 1000)
Corporate Personnel (annual for 5 years):			
1 Project Leader	@ 55 k		55.00
2 Senior Engineers	@ 35 k		70.00
3 Engineers	@ 24 k		48.00
2 Clerical	@ 12 k		24.00
			$ 197.00
		10 % Fringe	+ 19.7
			$ 216.70
		50 % Overhead	+ 108.35
			$ 325.05
Legal Fees (annual for 5 years):			
			$ 200.00
Site Administration (during one year construction period)			
1 Site Manager	@ 40 k		40.00
1 Assistant Site Manager	@ 35 k		35.00
1 Foreman	@ 28 k		28.00
1 Site Radiation Safety Officer	@ 35 k		35.00
1 Contracts Coordinator	@ 24 k		24.00
1 Radiation Safety Technician	@ 15 k		15.00
1 QA and Safety Supervisor	@ 26 k		26.00
1 Customer Service Coordinator	@ 24 k		24.00
1 Waste Shipment Scheduler	@ 16 k		16.00
1 Billing/Accounting Personnel	@ 12 k		12.00
2 Secretarial	@ 9 k		18.00
			$ 273.00
		10 % Fringe	+ 27.3
			$ 300.3
		50 % Overhead	+ 150.15
			$ 450.45

For the example reference disposal facility presented in Appendix E, the total capital investment is the sum of the direct and indirect capital costs, that is:

$$\begin{aligned} \text{Investment} &= 7{,}452{,}050 + 0.73\ (7{,}452{,}050) \\ &= 1.73\ (7{,}452{,}050) \\ &= \$12{,}892{,}000 \end{aligned}$$

2.3 Annual Fixed Capital Charge

The annual charge for the capital represented by the total investment includes such items as interest on borrowed money, return on equity, depreciation, taxes, and insurance. Calculation of annual fixed charges for a real disposal facility can become quite complicated; however, for the purposes of this appendix these charges are assumed to be calculated as a constant fixed percentage (the fixed capital charge rate) of the initial total investment cost, carried out over the 20-year operating life of the facility. The fixed charge rate can also be considered to be the ratio of the total, annual capital charge to the total capital investment.

To estimate the annual fixed charge rate, some typical fixed charge rates associated with nuclear fuel cycle facilities may be examined. One DOE document prepared by Battelle, Pacific Northwest Laboratories (PNL) provides an estimate of the fixed charge rate for a large private company, based upon a number of assumptions regarding the cost of money, federal and state income tax rates, insurance and contingencies, depreciation, and estimated site operating life (Ref. 2). Similar estimates (based on somewhat similar assumptions) may be found in an extensive series of studies by Oak Ridge National Laboratories (ORNL) on the costs and benefits of installation of additional airborne effluent treatment equipment in nuclear fuel cycle facilities. A typical document in this series is reference 3. A summary of the assumptions and fixed charge rates obtained from the DOE and ORNL references, are shown below.

	DOE	ORNL
Plant lifetime (years)	15-20	15
Capital Investment-bonds	25%	30%
Capital Investment-equity	75%	70%
Bond Interest rate	8%	5%
After tax return on equity	12%	16%
Federal Income Tax Rate	48%	50%
State Income Tax Rate	6.5%	3%
Annual Property Taxes and Insurance	7%	3.8%
Weighted Cost of Money	10%	
Investment Credit Rate	7%	N. A.
Fixed Charge Rate	23-25%	24%

In the ORNL document, the 5% bond interest rate was characterized as being probably somewhat low. ORNL also noted that increasing it to 8% would increase the fixed charge rate to about 26%.

For the purposes of this appendix, a fixed charge rate of 25% is assumed. This rate is also consistent with an assumed nuclear facility fixed charge rate in WASH-1538 ("Final Environmental Statement Concerning Proposed Rule-making Action: Numerical Guides For Design Objectives and Limiting Conditions For Operation to Meet the Criterion "as Low as Practicable" For Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents") (Ref. 3).

2.4 Total Capital Costs

Total capital costs are estimated as the product of the total capital investment times the annual fixed change rate (25%) over a period of 20 years, times a profit margin. For the purposes of this appendix, operating a disposal facility is taken to be a high-risk business venture, and a profit margin of 20% is assumed. Therefore,

Total capital costs = Direct Costs X Indirect costs X Annual Fixed Charge X Profit.
= Direct Costs X 1.73 X 0.25 X 20 X 1.20
= 10.38 Direct Costs

For the example reference disposal facility,

Total capital cost = 10.38 ($7,452,050)
= $77,352,300.

3. OPERATIONAL COSTS

The operational costs consist of the labor, equipment, materials and supplies required to conduct waste receipt and disposal activities. Included in these costs are overhead, contingency and profits, as well as the costs of site monitoring. The necessary costs for providing financial guarantees such as security bonds or letters of credit are included under postoperational costs. While they are incurred during operations, they are a function (as based on annual premiums) of the projected postoperational costs. To the extent that estimated postoperational costs change, the resultant costs of financial guarantees will change.

3.1 Direct Operational Costs

Total direct operational costs over the 20-year life of the disposal facility are estimated for the following cost components:

- Operations and maintenance;
- Disposal cell construction;
- Heavy equipment leasing;
- Corporate administrative and legal overhead;
- Payroll;
- Utilities and supplies;
- Environmental monitoring; and
- Regulatory costs.

Operations and maintenance costs include costs associated with routine operation and maintenance (upkeep) of site grounds, office and miscellaneous other light equipment, buildings, site facilities, and other structures such as roads, fences, lighting, etc. These costs are estimated at 10% of the capital outlay for these grounds, buildings, facilities, and other structures per year. (For the reference facility, this would total approximately 10% of $2,313,250 per year, or about $231,325 per year.)

Disposal cell construction takes place continuously during facility operation; therefore, costs for disposal cell construction are included under operational costs rather than capital costs. Construction operations include clearing away existing foliage, excavation of disposal cells, installation of standpipes and French drains, backfilling and compacting with heavy machinery, seeding and mulching, and emplacement of markers and monuments. Costs for disposal cell construction include those associated with equipment use (including fuel and lubrication), labor, and materials. For the reference facility, labor and equipment costs are included as part of costs for payroll, heavy equipment leasing, and consumables.

Estimated disposal cell materials and surveying costs are summarized on Table Q.2. Costs for 150 mm (6" I.D.) polyvinyl chloride (p.v.c.) standpipes (three to a trench) are estimated based upon consideration of reference 5. The cost for gravel placed within the French drain is estimated at $\$6.50/m^3$ ($\$5/yd^3$). Costs for grass seed and mulching materials are estimated based upon Reference 6. Costs for cornermarkers and monuments are estimated from information in reference 5. The cornermarkers and monuments are assumed to be made of polished red granite slabs, at $\$18.30/ft^2$ for a 4" slab. Each disposal trench has four 30" X 4" X 4" cornermarkers and one 30" X 16" X 4" monument. Hourly surveying charges are taken from Reference 6.

Equipment leasing costs are costs required to lease construction and waste handling equipment for use at the site (e.g., cranes, trucks, tractors, fork lifts, etc.) over a 20 year facility operating period. As stated above, operators of an actual facility may own part of the equipment and lease part of the equipment used at the facility. Assuming that the equipment is owned would require developing a number of additional assumptions regarding the fraction of owned equipment, how it was purchased (new, used), the financial arrangements regarding the purchases, and the operating life of the equipment prior to replacement. For this appendix, then, it is more straightforward to assume that all equipment is leased. Leasing costs may be obtained from standard guides for estimating construction costs (Ref. 5). A summary of the equipment requirements assumed for the reference facility is included as Table Q.3.

Corporate administrative costs are estimated at an average of $300,000 per year over the operating life of the facility. In addition, legal fees are estimated at an average of $150,000 per year.

Payroll costs are the largest component of the total expenses incurred during site operations. Payroll costs include personnel directly involved in the disposal operations, as well as site administrative and support personnel.

Table Q.2 Trench Construction Materials and Surveying Costs

A.	Standpipes	
	30 ft. of 6" p.v.c standpipe @ \$2.45/ft* 3 standpipes per trench = \$220.50/trench 3 standpipe casings @ \$150/standpipe = \$450/trench* 58 trenches @ \$670.50/trench	\$38,889
B.	French drain	
	(.6m X .6m X 180m) = 55 m^3/trench = 85 yd^3/trench gravel @ \$5/yd^3 = \$425/trench 58 trenches @ \$425/trench	\$24,650
C.	Seed and mulch	
	1.5 acres per trench materials = \$295/acre* 58 trenches X 1.5 acres X \$295/acre	\$25,665
D.	Cornermarkers and monuments	
	granite markers @ \$18.30/ft^2 for 4" slab** cornerstones = 4 X 30" X 4" = 3.33 ft^2 monuments = 30" X 16" X 4" = 3.33 ft^2 58 trenches X 6.67 ft^2 X \$18.30/ft^2	\$7,111
E.	Surveyor	
	surveyor @ \$60/hr assume 8 hrs/trench 58 trenches X 8 X \$60/hr	\$27,840
	Total:	\$124,155
		(\$2140.60/trench)

*Estimate based upon information obtained from Reference 5.

**Estimate based upon information obtained from Reference 4.

Table Q.3 Equipment Leasing Costs

No.	Equipment	Duration	Rate		Cost
1	Welder/Generator	240 months	@ $1500/mo	=	$ 360,000
1	40 Ton Crane	240 months	@ $4500/mo	=	1,080,000
1	100 Ton Crane	240 months	@ $6400/mo	=	1,536,000
4	Four Wheel Drive Vehicles	240 months	@ $ 800/mo	=	768,000
5	Pickups	240 months	@ $ 750/mo	=	900,000
2	Forklifts	240 months	@ $1000/mo	=	480,000
2	Crawler Tractors	240 months	@ $4200/mo	=	2,016,000
2	Farm Tractors	240 months	@ $ 800/mo	=	384,000
2	Pan Scrapers	240 months	@ $8000/mo	=	3,840,000
6	Miscellaneous Corporate Vehicles	240 months	@ $ 600/mo	=	864,000
					$12,228,000

Source: Reference 5

The assumed payroll costs per job function are listed in Table Q.4. A 10% fringe is added to the base personnel costs; a 50% overhead is then calculated from the combined base and fringe charges.

Environmental monitoring costs involve costs associated with analysis of environmental samples collected as part of the facility environmental monitoring program. The assumed operational environmental monitoring program for the reference facility is shown as Table Q.5. All gamma-isotopic, HTO, and ^{131}I sample analyses are assumed to be performed using offsite services. Costs are estimated based upon: (1) an assumed average cost of $50 per analysis of atmospheric, soil and vegetation, well water, and sump samples (530 analyses per year), and (2) an assumed charge of $200 per year for TLD analysis.

Regulatory costs include costs associated with license renewals, inspection fees, and amendments, and are listed in Table Q.6. Assuming that the disposal license is renewed every 5 years, the licensee would then undergo 3 license renewals over the 20 year operating life of the facility. NRC renewal fees would run approximately $100,000 per renewal. In addition, the licensee is assumed to prepare an environmental assessment of facility operations for each renewal. Each assessment is assumed to include an update of the facility closure plan, including an update of funding assessments. A final site closure plan will be prepared for NRC approval prior to implementation of the plan. An NRC review charge would also be levied on this final plan. Assuming that the licensee expends approximately $100,000 to prepare each of the 3 license renewals as well as the final closure plan, the total administrative costs for license renewal and facility closure would be approximately $800,000 over the operating life of the facility. Also included are NRC inspection fees which are assumed to total approximately $40,000 over 20 years, assuming 2 inspections per year. Finally, fees for license amendments are included, assuming one major amendment and ten minor amendments over the operating life of the facility.

Table Q.4 Reference Disposal Facility Payroll

No.	Job	Annual Salary($)	Extended Total($)
	Senior Staff		
1	Site Manager	40,000	40,000
1	Executive Secretary	12,000	12,000
1	Site Radiation Safety Officer	35,000	35,000
1	Assistant Site Manager	35,000	35,000
1	Foreman	28,000	28,000
1	Operations Manager	26,000	26,000
1	QA & Safety Supervisor	26,000	26,000
1	Office Manager	24,000	24,000
1	Security Chief	25,000	25,000
1	Librarian (Records)	12,000	12,000
1	Customer Service Coordinator	24,000	24,000
1	Contracts Coordinator	24,000	24,000
	Support Staff		
4	Waste Shipment Schedulers	16,000	64,000
2	Billing/Accounting Personnel	12,000	24,000
4	Security Personnel	12,000	48,000
4	Secretarial Personnel	9,000	36,000
	Staff		
3	QA Technicians	14,000	42,000
8	Radiation Safety Technicians	15,000	120,000
8	Heavy Equipment Operators	21,000	168,000
13	Semi-Skilled Laborers (includes mechanics)	15,000	195,000
12	Unskilled Laborers	10,000	120,000
70			$1,128,000

Table Q.5 Reference Facility Operational Enviromental Monitoring Program

Sample Description	No. of Locations	Type	Media	Frequency of Analysis	Type of Analysis
External Gamma	50	Continuous	TLD	Quarterly	Exposure
Atmosphere	3	Continuous	Parti-culate Filter	Daily	Gross Beta-Gamma
			Parti-culate Filter	Weekly	Gamma Isotopic
			Charcoal Cartridge	Weekly	I-131
Soil and Vegetation	10	Grab	Soil and Vegetation	Quarterly	Gross Beta-Gamma Gamma Isotopic Gross Alpha HTO
Offsite Wells	5	Grab	H_2O	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Site Boun-dary Wells	10	Grab	H_2O	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Disposal Area Wells	15	Grab	H_2O	Quarterly	Gamma Isotopic Gross Alpha HTO
Disposal Trench Sumps	As con-structed	Grab	H_2O	Monthly	Gamma Isotopic Gross Alpha HTO

Estimated annual costs: $26,700.

Table Q.6 Summary of Regulatory Costs

		Costs (X 1000)
1.	3 Environmental assessments for license renewals (@ $100 k each)	$ 300
2.	3 license renewal fees (@ $100 k each)	$ 300
3.	1 Final site closure plan	$ 100
4.	1 Closure plan review fee	$ 100
5.	Inspection fees (assume 2 per year over 20 years)	$ 40
6.	License Amendments	
	Assume: 1 major amendment	$ 291
	10 minor amendments	$ 7
		$1,138

The cost of consumables (utilities, fuel, supplies, etc.) are estimated at $200,000 per year, which is an estimate based upon consideration of consumable costs estimated by DOE in reference 8.

For the reference disposal facility, total direct operational costs are estimated as follows:

Operating Costs Over 20 years (X 1000)

1.	Operations and maintenance (10% of buildings, facilities, and light equipment over 20 years)	4,626.5
2.	Disposal cell materials (58 trenches)	124.2
3.	Heavy equipment	12,228
4.	Payroll:	
	o Base	22,560
	o Fringe	2,256
	o Overhead	12,408
5.	Corporate administration (@ $300 k/yr)	6,000
6.	Legal fees (@ $150 k/yr)	3,000
7.	Environmental monitoring	534
8.	Regulatory costs	1,138
9.	Consumables (utilities, fuel, supplies, etc.) (@ $200 k/yr)	4,000
		$68,875

3.2 Indirect Operational Costs

Indirect operational costs are approximated as a percentage of the total direct operational costs and are assumed to consist of a 30% contingency allowance. Operational costs prior to profit are therefore calculated as the following.

Costs = 1.3 (Direct costs).

For the reference disposal facility, this comes to:
1.3 x \$68.9 million = \$89.5 million.

3.3 Total Operational Costs

Again, a profit of 20% is assumed. Total operational costs are estimated as the following:

Total operational costs = (1.2)(1.3)(Direct Costs)
= 1.56 (Direct Costs)

For the reference facility, total capital and operational costs equal the following:

Total Costs = 10.38 (Direct capital costs)
+ 1.56 (Direct operational costs)
= 10.38 (7,452,100) + 1.56 (\$68,875,000)
= \$184,797,000
= \$185./m^3
= \$5.23/ft^3

4. POSTOPERATIONAL COSTS

Postoperational costs are composed of two components: (1) costs for facility closure following the end of the facility 20-year operating life, and (2) costs for institutional control of the facility after closure. In this appendix, costs for closure are assumed to be borne by the licensee. To fund closure activities, the licensee is assumed to set aside a sum of money on an annual basis for investment and accrual. This is represented in this appendix by a surcharge (\$ per m^3 of waste) on waste received at the disposal facility. Monies received from this surcharge are assumed to be placed into an interest-bearing investment fund. However, to ensure that funds will be available to implement closure should for some reason the site be closed earlier than scheduled, the projected costs for closure are assumed to be protected by a surety mechanism obtained by the licensee. Funds for institutional control are assumed to be obtained through a surcharge (\$ per m^3 of waste) placed upon the waste received at the facility. Monies obtained through the surcharge mechanism are placed in an interest-bearing state operated investment fund.

The remainder of this section is divided into two subsections: Section 4.1 addresses closure and Section 4.2 addresses institutional control. Each subsection develops scenarios regarding the specific level of activities required. That is, two levels of closure activities (and costs) are developed (e.g., high, and low), as well as three levels of institutional control activities (high, medium and low). The possible need for long-term contingency (remedial) actions are also addressed in Section 4.2.

Section 4.0 is then followed by a Section 5.0 which briefly illustrates how closure and institutional control costs may vary depending upon assumptions regarding funding mechanisms (surety bonds, letters of credit, sinking funds) as well as interest and inflation rates.

4.1 Closure

Closure activities involve final decontamination and dismantlement of buildings and other structures, as well as preparation of the disposal facility for institutional control by the site owner. Closure activities are referenced in this section to the reference disposal facility discussed in Appendix E. Closure costs are estimated based upon the following factors:

- Building decontamination and demolition;
- Final grounds preparation;
- Onsite disposal of demolished buildings and other waste material;
- Personnel costs (including fringe and overhead);
- Supplies and utilities;
- Equipment costs; and
- Environmental monitoring costs.

As an illustration in this appendix, two levels of closure costs are estimated: low and high. These two scenarios are discussed below.

4.1.1 Low Scenario

For the low scenario, final closure of the reference facility is assumed to require approximately two years and mainly involves dismantling and decontaminating site buildings, disposal of wastes produced during dismantlement and decontamination operations, and final site seeding and contouring.

Three of the six buildings on the reference disposal facility--i.e., the administration building, the health physics/security building, and the site warehouse,--are located in the administrative area of the site and should be essentially free of contamination. The administration building and the warehouse--are dismantled and sold for salvage. The health physics/security building is left standing for use by the site owner during the institutional control period. Of the remaining three site buildings, only the waste activities building is expected to have appreciable levels of contamination. This building is decontaminated to the extent practical and demolished, as is the site garage and the site shed. To accommodate the waste produced during dismantlement and decontamination operations, an additional small trench is excavated. The volume of waste produced during these operations is estimated to be relatively small--about 1130 m^3 (40,000 ft^3) (Ref. 6).

For the low scenario, there is assumed to be little effort to recontour the disposal site land. The trench covers are left mounded. The final disposal trenches are filled, capped, graded, and seeded with a grass cover. During this time period, the licensee makes a final survey of the disposal area to determine direct radiation levels. All parts of the disposal area are certified as having radiation levels at essentially background levels.

A summary of the estimated costs are included as Table Q.7. Based upon consideration of the site closure and stabilization plans of an existing disposal facility, building demolition is estimated to cost approximately $300,000, assuming that a private contractor is hired to perform these operations (Ref. 6).

Estimated personnel costs are also shown in Table Q.7, and fringe and overhead are calculated as above. For this appendix, building demolition, waste disposal, and most of the final site preparation is assumed to require approximately a year's effort. However, another year at reduced licensee effort is assumed to be needed for final site surveillance activities prior to license termination.

Supplies and utilities are estimated as 10% of base personnel costs. Environmental monitoring costs are estimated assuming that the operational environmental monitoring program is continued during the closure period. Total closure costs are estimated at about $ 1 million.

4.1.2 High Scenario

In this scenario, a complete site restabilization program is assumed to be carried out at site closure. This program serves to accelerate the compression of wastes and waste containers in the disposal cells. The program is intended to enhance the integrity of the disposal cell covers and therefore reduce the amount of water potentially infiltrating into the disposed waste. The restabilization program involves: (1) stripping off the existing trench caps, (2) use of vibratory compaction to accelerate disposal cell compression, (3) backfilling the resultant compressed (depressed) areas, (4) reconstruction of the trench caps, and (5) revegetation of the trench caps, including fertilizing, seeding, and mulching.

The restabilization program is carried out as an addition to the decontamination, demolition, and final waste disposal activities discussed for the low scenario. Total closure operations are estimated to require approximately 4 years of effort. This results in greatly increased closure costs as shown in Table Q.8--i.e., up to about $3 million. Much of the additional costs are caused by delaying site stabilization activities until closure. If the same compaction and stabilization activities were carried out all through site operations, then overall costs should be reduced.

4.2 Institutional Control Program

For this appendix, institutional control activities are assumed to be carried out by an agency of the state in which the disposal facility is located. Funds for institutional control are provided by a tax exempt sinking fund into which money is placed during site operations from a surcharge placed upon waste received at the facility during the operating life. For this section, estimated funding levels are presented in constant (1980) dollars. The effects of interest and inflation are discussed in the next section.

Table Q.7 Estimated Closure Costs--Low Scenario

I.	Building Demolition		$300,000
II.	Waste Disposal Materials and Survey		
	40,000 ft^3 = 1133 m^3 of waste, need 22,700 m^3 of disposal space, assuming 50% efficiency. Assume one 7m X 47m X 8m trench		
	a) Standpipes 30 Ft of 6" p.v.c. standpipe @ $2.45/ft 2 standpipes per trench = $300/trench well casings @ $150/pipe = $300/trench		$ 547
	b) French drain (.6 m x .6m x 47m) = 17m^3 = 22 yd^3 22 yd^3 @ $5/$yd^3$		$ 2,582
	c) Seed and mulch 0.12 acres @ $295/acre		$ 35
	d) Cornermarkers & monuments 6.67 ft^2 x $18.30/$ft^2$		$ 480
	e) Surveyor Surveys @ $60/hr Assume 8 hrs/trench		$ 480
			$ 1,294
III.	Personnel		
	1st year: 1 Site Manager		40,000
	1 Foreman		28,000
	2 Security		24,000
	1 Radiation safety officer		35,000
	1 Radiation safety technician		14,000
	5 Semiskilled laborer		75,000
	2 Unskilled laborer		20,000
			$236,000
		Fringe	23,600
		Overhead	129,800
			$389,400
	2nd year: 1 Site manager		40,000
	1 Radiation safety technician		14,000
	1 Semiskilled laborer		15,000
			69,000
		Fringe	6,900
		Overhead	37,950
			$113,850

Table Q.7 (continued)

IV.	Consumables		
	(10% of base personnel costs) 2 years:		$ 30,500
V.	Equipment		
	1 4WD vehicle	24 months @ $ 800/mo	19,200
	1 Crawler tractor	6 months @ $4200/mo	25,200
	1 Farm tractor	24 months @ $ 800/mo	19,200
	1 Pan scraper	12 months @ $750/mo	48,000
	1 Pickup	12 months @ $750/mo	9,000
			$120,600
VI.	Environmental Monitoring		
	2 years @ $26,700/yr		$ 53,400
		Total	$1,009,044

For the cost estimates, 3 levels of institutional control are assumed: a high level, a moderate level, and a low level. For each level, costs are broken down into two basic activities:

- recordkeeping and administrative support; and
- site surveillance and maintenance (assumed to be contracted by the state agency to individuals or to a private firm)

Recordkeeping and administrative support costs are calculated by estimating the number of man-hours required by the state to administer the institutional control program for the facility. Administrative support costs include personnel salaries, overhead, utilities, etc., and are basically an estimate of the average cost to a government of one year's labor by a government employee. At the Federal level, administrative costs run at about $80,000 to $100,000 per man-year. State costs are generally lower and an approximate figure of $50,000 per man-year is used in this appendix.

The level of effort expended by the state is assumed to be a function of the degree of stability of the facility, and the surveillance, maintenance, and monitoring activities required for the facility. In this appendix, the level of effort is assumed to range from a quarter of a man-year to 3 man-years, depending upon the degree of site stability achieved.

Disposal facility surveillance and maintenance costs are calculated assuming that a company or individuals are contracted by the state for surveillance, maintenance, and environmental monitoring activities. These costs are assumed to include costs for:

Table Q.8 Estimated Closure Costs--High Scenerio

I.	Building Demolition		$ 300,000
II.	Waste Disposal (Survey and Materials)		1,294
III.	Restabilization		
	Total disposal area: 86 acres = 348,000 m^2		
	a) Strip cap (1 m) 348,000 m^3 = 455,000 yd^3	@ $0.75/yd^3*	341,250
	b) Vibratory compaction assume one week per trench	= 58 weeks = 13 months, 2 weeks	
	1 vibratory compactor 3 man crew	@ $1,950/mo, $675/wk* @ $15/hr x 40 hr/wk	131,100
	c) Replace cap (1.15 m) 400,200/m^3 = 523,380 yd^3 @ $0.75/yd^3		392,438
	d) Compact Cap @$0.55/m^3		220,100
	e) Vegetate @$500/acre		43,000
			$1,127,888
IV.	Personnel		
	Year 1:		$ 389,400
	Years 2-3:		
	1 Site manager		40,000
	1 Foreman		28,000
	1 Radiation safety officer		35,000
	2 Radiation safety technician		28,000
	3 Semi-skilled laborer		45,000
	3 Unskilled laborer		30,000
			206,000
		Fringe:	20,600
		Overhead:	113,300
			339,900
		x 2 years	679,800
	Year 4:		113,850
			$1,183,050

Table Q.8 (continued)

IV.	Consumables	
	(@ 10% of base personnel costs)	$ 70,200
V.	Equipment	
	1 Crawler tractor 6 mo @ $4200/mo	25,200
	1 Farm tractor 48 mo @ $800/mo	38,400
	1 Pan scraper 6 mo @ $8000/mo	48,000
	1 4WD vehicle 48 mo @ $800/mo	38,400
	1 Pickup 36 mo @ $750/mo	27,000
		$ 177,000
VI	Environmental monitoring	
	4 years @ $26,900/yr	$ 106,800
	air sampler purchase and install	
	10 samplers @ $900/sampler	9,000
	air sampler analyses	
	10 samples x 50 samples/yr x $50/sampler	50,000
	2 years @ $25k/yr	$ 165,800
	Total:	$3,025,232

*Ref. 5.

- o personnel;
- o personnel fringe and overhead;
- o supplies;
- o equipment;
- o environmental monitoring sample analysis; and
- o contractor fees.

As long as the disposal facility is in a stable condition, then the institutional control activities could involve persons whose role would be little more than that of a caretaker. These activities could involve facility inspections, collecting environmental samples for analysis, and minor maintenance (if required) of fences, site grounds, and so forth. These activities would probably require some, but not extensive, knowledge of radiation, radiation safety, and radiation equipment.

However, if modest to extensive subsidence were a recognized problem, or if there was concern that subsidence was a potential problem, then much greater experience with radiation and contamination control and radioactive waste management would be needed. In these cases, a company experienced in radioactive waste disposal is assumed to be contracted to run the facility. The need to employ the services of such a company and the need to employ the company more-or-less full time at the facility results in considerable additional expenses to the state. Expenses would include personnel payroll and overhead, supplies, equipment and contractor's fees.

In this appendix, four levels of contractor's activities are assumed. A six-man crew is assumed to be associated with a relatively high level of maintenance activities. These activities do not, however, include potential costs for occasional pumping of trench sumps, treating and solidifying any liquid collected, and onsite disposal of solidified waste. A 4-man crew is associated with a more moderate but still significant level of site maintenance. There is projected to be, however, little or no need for trench pumping activities. The 2-man crew is associated with a low level of site maintenance. Such maintenance activities may actually not be required; however, they are conservatively included. As discussed above, the one-man crew is basically a caretaker.

The personnel required for each crew are estimated in Table Q.9. As shown, a 6-man crew is estimated to involve total base personnel salaries of $109,000 annually, while the 4-man crew is estimated to involve total base personnel salaries of $79,000. The 2-man crew involves a base salary of $43,000 and that of the caretaker, $20,000. There is also assumed for each crew a fringe of 10% and an overhead charge of 50%.

Supplies are estimated by assuming that the costs for the supplies needed are a fraction (10%) of the base personnel salaries. The more personnel are required to operate the site, the greater the outlay for supplies and utilities is likely to be.

Equipment costs are geared to the level of effort by onsite personnel, and by the size of the work crew. Assumed equipment use and charges are illustrated in Table Q.10. The 6-man work crew is assumed to require a relatively high level of equipment use while the 4-man crew is assumed to require a relatively moderate level of equipment use. The 2-man crew is assumed to only have very low equipment requirements.

Environmental monitoring costs are estimated by again assuming 3 levels of environmental monitoring needs depending upon the stability of the facility--i.e., a high level, a moderate level, and a low level. A facility which requires a great deal of maintenance would also require a high environmental monitoring effort. This is because there are more activities at the site which might involve handling radioactive material, in addition to an inherent increased level of concern regarding the long term impacts of an unstable site. On the other hand, monitoring costs would be expected to be significantly reduced at a stable site. A summary of the types and frequencies of environmental

Table Q.9 Personnel Requirements for Institutional Control

Level of Effort	Personnel	
High (6-man crew)	1 Site manager	$ 40,000
	1 Health physics technician	14,000
	3 Semi-skilled laborer	45,000
	1 Unskilled laborer	10,000
		$109,000
	Fringe :	10,900
	Overhead:	59,950
		$179,850
Moderate (4-man crew)	1 Site manager	$ 40,000
	1 Health physics technician	14,000
	1 Semi-skilled laborer	15,000
	2 Unskilled laborer	10,000
		$ 79,000
	Fringe :	7,900
	Overhead:	43,450
		$130,350
Low (2-man crew)	1 Foreman	$ 28,000
	1 Semi-skilled laborer	15,000
		$ 43,000
	Fringe :	4,300
	Overhead:	23,650
		$ 70,950
Very Low (1-man)	1 Caretaker	$ 20,000
	Fringe :	2,000
	Overhead:	11,000
		$ 33,000

Table Q.10 Equipment Use During Institutional Control (in months per year)

	Level of Use		
Equipment	High	Moderate	Low
4WD Vehicle	12	0	0
Pickup	12	12	6
Crawler Tractor	6	0	0
Farm Tractor	12	6	3
Estimated Costs	$53,400	$26,400	$6,900

sampling assumed to be undertaken for each level of monitoring activity is presented in Table Q.11, along with the overall estimated costs for sample processing and analysis.

The fee is again assumed to be a fraction of the contractor's total expenses at the facility. In this case, as maintenance activities are assumed to involve a relatively low level of business risks, the fee is assumed to be 10% of the total expenses.

A summary of the costs over 100 years of institutional control (including state administration costs, as well as costs for site personnel, supplies, equipment, monitoring, and the constructor's fee) is presented as Table Q.12. As shown, for each level of institutional control activities, costs for 3 time periods are presented. The time periods considered are 0 to 10 years, 11 to 25 years, and 26 to 100 years. The different time periods are presented due to the expectation that the disposal facility would tend to naturally stabalize over time. This is similar to the approach taken by Battelle-Pacific Northwest Laboratories (PNL) in NUREG/CR-0570 (Ref. 9). However, NRC staff experience has been that initial subsidence at disposal facilities is generally characterized by a 7 to 10 year time frame rather than a zero to 5 year time frame assumed by PNL.

The low level of maintenance costs are in the same range as the PNL projections for minimal long-term care costs at an eastern site over 100 years. (Ref. 9). However the estimated costs may be conservatively high. As long as there is some assurance that the facility is in a stable condition, it may be possible to get by with considerably less expenditures.

Table Q.11 Estimated Long-Term Environmental Monitoring Activities

	High		Moderate		Low	
Sample Description	No. of Loc.	Frequency	No. of Loc.	Frequency	No. of Loc.	Frequency
TLD*	30	quarterly	10	quarterly	0	
Atmospheric	3	daily gross beta-gamma weekly gamma isotopic	1	daily gross beta-gamma weekly gamma isotopic	0	
Soil and Vegetation	10	quarterly	10	semi-annual	10	semi-annual
Offsite Wells	5	semi-annual	2	semi-annual	2	annual
Boundary Wells	10	semi-annual	5	semi-annual	5	annual
Disposal Area Wells	15	quarterly	15	semi-annual	5	semi-annual
Disposal Trench Sumps	58	monthly	58	semi-annual	58	semi-annual
Estimated costs	$19,200		$8,400		$3,100	

*Thermoluminescent dosimeter.

The estimated costs for the high level of maintenance, however, may be too low. For example PNL has suggested a possible 25% contingency for unforseen events (Ref. 9). Unforseen events could include water management problems ranging from periodic withdrawal of water from disposal trenches and solidification, to large scale dewatering activities brought about by an extensive occurrence of the bathtub effect.

Table Q.13 summarizes an estimate of the additional costs that could arise from a relatively moderate scale water accumulation problem at the reference facility. In this case, a total of 25,000 gallons of water is assumed to be pumped from the disposal trenches per year. Leachate withdrawn from disposal trenches is assumed to be solidified in cement (at a volume increase factor of 1.4) and disposed onsite. Costs for leachate solidification are estimated to be

Table Q.12 Estimated Annual Institutional Control Base Costs

Level of Effort	Adm	Contractor Costs ($x 1000 per year) Personnel	Supplies	Equipment	Monitoring	Fee	Total
High							
0-10	150	179.85 (high)	10.9	53.4 (high)	19.2 (high)	26.3	439.65
11-25	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
26-100	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
Moderate							
0-10	100	130.35 (mod)	7.9	26.4 (mod)	19.2 (high)	18.4	302.3
11-25	50	70.95 (low)	4.3	6.9	8.4	9.06 (low)	149.6 (mod)
26-100	50	33 (care)	2.0	- (nil)	3.1 (low)	-	88.1
Low							
0-10	50	70.95 (low)	4.3	6.9 (low)	8.4 (mod)	9.06	149.6
11-25	25	33 (care)	2.0	- (nil)	3.1 (low)	-	63.1
26-100	12.5	33 (care)	2.0	- (nil)	3.1 (low)	-	50.6

Table Q.13 Small to Moderate Water Accumulation Costs

I.	Personnel	
	1 additional semi-skilled laborer @ $15,000/yr	$ 15,000
	Fringe & Overhead	$ 9,750
	Supplies @ 10%	$ 1,500
II.	Solidification Equipment	
	Cement solidify into 55 gallon drums @ 25,000 gallons per year, 1:4 VIF $2.50/gal*	$ 62,500
	637 drums @ $20/drum* (Price includes equipment, cement, labor & fuel)	$ 12,740
III.	Disposal Trench Materials Costs	
	Continuously operated trench for 10 years ($2650\ m^3$ disp. space) Trench dimensions = $8\ m \times 47\ m \times 8\ m = 3008\ m^3 = 3934\ yd^3$	
	a) Standpipes	
	30 ft. of 6" p.v.c standpipe @ $7/ft	
	2 standpipes per trench @ $210/pipe	$ 420
	standpipe casings @ $150/casing	$ 300
	b) French drain	
	$(.6m \times .6m \times 47m) = 17m^3 = 22\ yd^3$	
	gravel fill @ $\$5/yd^3$	$ 177
	c) Seed and mulch	
	$550\ m^2$ =	$ 40
	d) Cornermarkers and monuments	
	Polished red granite: $6.7\ ft^2$ @ $\$18.30/ft^2$	$ 122
	e) Surveyor	$ 480
	$60/hr @ 8 hr/trench	
	Total:	$ 1,539
	Cost per year:	$ 154
IV.	Disposal equipment**	
	1 panscraper, 6 months @ $8000/mo	$ 48,000
	pumping equipment, 12 months @ $500/mo	6,000
		$ 54,000

Table Q.13 (continued)

V.	Additional environmental monitoring		
	10 extra atm. samplers @ 50 samples/yr 100 extra sump samples/yr. $50/sample		$ 30,000
		Subtotal:	$185,644
VI.	Contractor's Fee		
	10%		$ 18,564
		Total per yr:	$204,208
	Total operating costs over 10 years = $2,042,080		
	Purchase and install 10 atm samplers @ $900 apiece = $9,000	Total cost =	$2,051,080

*Ref. 10.

**Ref. 5.

approximately $2.50 per gallon, which includes installation costs and cement. The figure $2.50/gallon to solidify leachate is on the low end of a range of estimates of moderately sized cement solidification systems (maximum throughput of 25,000 gallons) analyzed by Dames and Moore (D&M) for use in solidifing evaporator bottoms at the Maxey Flats disposal facility. (The costs ranged from $2.25 to about $10 per gallon) (Ref. 10). Costs for 55 gallon drums are estimated at $20/drum (Ref. 10).

Disposal trench materials costs are estimated by assuming a disposal trench is operated continuously over a ten year time period. To represent additional equipment requirements, an additional pan scraper is assumed to be leased for 6 months per year.

As can be seen, the costs of solidifying 25,000 gallons of trench water per year would run about $204,208 per year or a total of $2,042,080 over 10 years.

The above costs are for a moderate water accumulation problem involving 25,000 gallons per year over 10 years time, and assumes that the persons maintaining the disposal facility are reasonably diligent in removing any accumulated liquids. It is therefore instructive to examine a potential case in which for some reason liquids are allowed to accumulate over several years prior to processing. This can occur at disposal facilities located in sites having highly impermeable soils as has been previously experienced at Maxey Flats and West Valley.

Table Q.14 summarizes the potential annual costs associated with pumping, processing, solidifying, and disposing of one million gallons of contaminated liquid per year. As shown, the initial installation charge for an evaporator and a demineralizer pretreatment system are estimated to be about $1.75 million, as installed (Ref. 11), while the annual operating charge is estimated to run about $70,000 per year. The assumed evaporator is a 10 gpm forced circulation evaporator/crystallizer having a volume reduction factor of between 178-208 (Ref. 12). The $1.75 million purchase and installation cost does not include the costs of any additional air cleaning system. Operating costs do not include costs for replacing ion exchange media in the demineralizer.

One million gallons of liquid processed per year is somewhat less than the annual quantity of contaminated liquid presently processed at the Maxey Flats disposal site (Ref. 12). Not all of the contaminated liquid processed at Maxey Flats is leachate pumped from the disposal trenches. Some of it is contaminated water from within a storage tank berm area. However, all of the liquid treated is treated as a direct result of the liquid accumulation problem in the disposal trenches. As shown, processing costs carried out over a number of years can grow to be quite expensive--e.g., 10 years of processing would total about $8.5 million.

Experience has shown that unless steps are taken to reduce or eliminate the accumulation rate, processing operations can continue over long time periods. For example, leachate pumping and treating operations at Maxey Flats have been carred out since 1973. However, it has only been within the last few years that the contaminated liquid processing rate has been greater than the accumulation rate (Ref. 12).

From Table Q.15, it can be seen that a complete site restabilization effort carried out over approximately two years could cost in the neighborhood of $1.7 million. This involves stripping off trench caps, compaction of the wastes, replacing and compacting the cap, and placement of vegetation. An extended period of intensive site surveillance would also probably be required to assure that the restabilization program had eliminated the water accumulation problem.

As long as the disposal facility is not placed in a stable condition, additional (contingency) long-term care costs can therefore range from approximately $1.7 million to $10 million. At a site with very permeable soils, water accumulation may not be a special problem, and additional costs could be just those associated with restabilization--i.e., $1.7 million ($167,800/yr). At sites with moderately permeable soils, additional long term costs could include those for a moderate amount of liquid treatment and a restabilization program.

Assuming 10 years of moderate leachate treatment activities along with a restabilization program, total contingency costs over 10 years could be as much as 3.67 million ($367,000/yr). For disposal facilities with very impermeable soils, experience has indicated that it is possible to create a situation where an extensive liquid treatment operation is required. Ten years of such treatment combined with a restabilization program could increase costs by about $10 million ($1,006,900/yr).

Table Q.14 Pumping, Processing, and Solidifying Costs for One Million Gallons of Contaminated Liquid Per Year

I.	Capital Costs	
	Purchase evaporator (Ref. 12)	$1,000,000
	Purchase ion-exchange pre-treatment system (Ref. 11)	$ 750,000
	Purchase and install 10 atm. samplers @ $900 apiece (Ref. 11)	9,000
		$1,759,000
II.	Yearly Costs	
	1) Equipment	
	Lease pump & hose @ $500/month (Ref. 5)	$ 6,000
	2) Labor Costs	
	2 semi-skilled laborers @ $15,000	
	2 unskilled laborers @ $10,000	
	30,000 + 20,000 =	$ 50,000
	Fringe	5,000
	Overhead	27,500
	Supplies	5,000
	3) Treatment Costs	
	Volume reduction factor = 200	
	Ion exchange 1 E6 gal/yr @$0.10/gallon (Ref. 13)	$ 100,000
	Evaporate 1 E6 gal/year @ $0.35/gallon (Ref. 12)	$ 350,000
	4) Solidification	
	Solidify 5,000 gallons of concentrated bottoms per year. Assume cement solidification, with 1.4 VIF, @ $2.50/gallon and $20 per 55-gallon drum	
	Solidification:	$ 12,500
	728 drums — Drum Charge:	$ 2,545
	5) Disposal Costs	
	7,000 gal solified waste per year requires 53 m³ of disposal space per year or 530 m³ of disposal space over 10 years. Assume continuously operated 4 m x 19 m x 8 m trench.	
	a) Standpipes	
	30 ft. of 6" pvc pipe @ $7/ft	
	2 standpipes per trench @ $210/pipe	$ 420
	Standpipe casings @ $150/casing	$ 300

Table Q.14 (continued)

b)	French drain (.6m x .6m x 19m) = $7 m^3$ = 9 yd^3 gravel fill @ $5/$yd^3$	$	72
c)	Seed and mulch 154 m^2 = 0.04 acre @ $295/acre		12
d)	Cornermarkers and monuments Polished red granite: 6.7 ft^2 @ $18.30/$ft^2$	$	122
e)	Surveyor $60/hr @ 8hr/trench		480
	Total:	$	1406
	Cost per year:	$	141
6)	Disposal Equipment Lease 1 pan scraper: 12 months @ $800/mo (Ref. 5)	$	9,600
7)	Additional Environmental Monitoring 10 samplers x 50 samples/yr 300 extra sump samples/yr $50/sample analysis	$	40,000
	Subtotal:	$	608,286
	Contractor's Fee @ 10%	$	60,829
	Total Yearly Costs	$	669,115
	Total Operating Costs Over 10 Years:	$	6,691,150
	Total Capital Costs:	$	1,759,000
	Total Costs Over 10 Years	$	8,450,150

5.0 FINANCING FOR CLOSURE AND INSTITUTIONAL CONTROL

The previous section investigated some scenarios for closure and institutional control and estimated potential costs in 1980 dollars. Appendix K of this environmental impact statement investigates a number of potential institutional mechanisms for assuring the availability of funds for closure and long term control. Some of the short-term (e.g., for closure) financial surety mechanisms considered in Appendix K are:

- Surety bonds purchased by a disposal facility operator from a surety company
- Cash deposits to a state or federal agency
- Certificates of deposit

Table Q.15 Site Restabilization Program

I.	Restabilization		
	(from Table Q.8)		$1,127,888
II.	Additional Personnel		
	1 Foreman		$ 28,000
	1 Radiation safety officer		35,000
	1 Radiation safety technician		14,000
	2 Unskilled laborer		20,000
			$ 97,000
			9,700
			53,350
			$ 160,050
		x2 years	$ 320,100
III.	Additional Equipment		
			0
IV.	Additional Supplies		$ 19,400
V.	Additional Environmental Monitoring 10 samplers @ 50 samples/yr $50/sample x 2 years		50,000
			$1,517,388
	Contractors Fee:		$ 151,739
			$1,669,127
		Purchase and install 10 atm samplers @ $900/sampler	9,000
			$1,678,127*

*If the restabilization program is combined with a moderate to large water accumulation program, then additional atmospheric samplers are already included. In this case, total costs = $1,619,127.

- <u>Deposits of securities</u> to a state or federal agency
- <u>Secured interests</u> in disposal facility operator's assets
- <u>Letters or lines of credit</u> from a financial institution
- <u>Self-Insurance</u> by the disposal facility operator.

Appendix K also investigates longer term financial surety mechanisms such as the current most common arrangement--that is, depositing monies obtained as a surcharge on received wastes into a state operated interest-bearing account. Other potential long-term funding arrangements are also investigated.

The purpose of this section is to provide an illustration of the effect of different funding arrangements (including different assumptions regarding interest rates, inflation rates, and so forth) and thus help to place Section 4 and Appendix K into better perspective. Actual funding arrangements for a particular disposal facility are expected to be fairly complicated and site-specific. A fairly simplified discussion, however, is provided below as an illustration.

5.1 Background

The following subsection provides a background discussion of a number of financial concepts used in this section. Much of the information in this subsection was obtained from information in Appendix E of NUREG/CR-0570 (Ref. 9) and from DOE (Ref. 8).

One important concept is that of the present value of money. The concept of present value allows a systematic treatment of the effects of expenditures, costs, and receipts of revenue over different time periods. The value of money changes as it is moved through time. In general, since presently available money can be put to a useful purpose, money has a greater value in the present than it would at some time in the future. For example, if S is the effective earning rate or interest rate, then the present value of one dollar due one year in the future is $1/(1 + S)$; similarly, the present value of that dollar earned n years in the future is $1/(1+S)^n$ (Ref. 14).

In terms of long-term care costs, the present value of these costs is equal to the capital required in a long term care fund. For example, assume that for each year over a total of n years, a constant amount of money (C) is expended. Then if the net rate of return on capital (the real interest rate) is equal to r, the present value (P) of all future costs is (Ref. 8):

$$P = C \frac{1 - (1+r)^{-n}}{r}$$

Assuming that C=\$100,000 and n=100 years, then the present value of all future costs as a function of alternative real interest rates are:

P ($ million)	r (%)
4.31	2.0
5.16	1.5
6.30	1.0
7.85	0.5
10.00	0
13.02	-0.5
17.32	-1.0
23.55	-1.5
32.70	-2.0

In the above example, the real interest rate is defined as the nominal interest rate minus the inflation rate divided by 1 plus the inflation rate, or

$$r = \frac{i - j}{1 + j}$$, where

i = the (nominal) interest rate, or the rate of return on capital invested in normal securities (i.e., bonds, certificates of deposit, and similar financial investments); and

j = the inflation rate, or the annual rate of increase in cost of goods and services, as determined by one or more of the nation's economic indicators.

This formula is an approximation which is somewhat of an overestimate when inflation occurs early in the time period of interest and somewhat of an underestimate when inflation occurs toward the end of the time period of interest.

As shown, the value of the real interest rate has a significant effect on the present value calculated. For example, at a zero net interest rate (interest rate equals inflation rate), the present value is merely the product of the annual costs ($100,000) times the period of interest (100 years), or $10 million. At a net interest rate of +1.0%, the present value drops to $6.3 million; at a rate of +2%, the present value drops to $4.31 million. In other words, at a real interest rate of +2.0%, a total capital of $4.31 million is all that is needed to provide for $100,000 of long term care per year over 100 years. One additional advantage of a net interest rate of +1.0% or higher is that the present value does not increase significantly for time periods beyond 100 years. For example, if (C) is still $100,000, and if r varies between +1% and +2.5%, then the present value over different time periods is as follows:

Present Value ($ million) as Function of R and n

	r (%)			
n (years)	+ 1	+ 1.5	+ 2	+ 2.5
100	6.30	5.16	4.31	3.66
200	8.63	6.33	4.91	3.97
300	9.50	6.59	4.99	4.00
500	9.93	6.66	5.00	4.00
1000	10.00	6.67	5.00	4.00
10^6	10.00	6.67	5.00	4.00

At a negative real interest rate, an opposite trend is seen. For example, at a rate of -1%, the present value is $17.32 million for n = 100 years. For the same negative interest rate and a time period of 200 years, the present value is $64.64 million; at 300 years, the present value is $193.91 million.

Determination of the long-term real interest rate is difficult. The real interest rate is a function of the inflation rate and the nominal interest rate and both of these rates fluctuate both over time and over different areas in the country. The interest rate, of course, varies depending upon the type of security chosen. The inflation rate is a function of the manner in which the rate is calculated--e.g., the types of commodities or services examined when calculating the inflation rate. For example, the change in the consumer price index is one indicator of inflationary trends, and the gross national product (GNP) deflator is another.

To illustrate, Table Q.16 is reprinted from the "Final Generic Environmental Impact Statement on Uranium Milling" (NUREG-0706) and provides a comparison of the long-term government bond rate, the change in the consumer price index, and the imputed real interest rate (Ref. 15). Table Q.17 is reprinted from a report prepared by the International Research and Technology Corporation (IR & T) for EPA regarding financial mechanisms for hazardous waste disposal facilities (Ref. 16). This table was computed under different assumptions than Table Q.16 and illustrates the real interest rate on ten year U. S. Government Securities from 1943 to 1967. These interest rates are seen to fluctuate from -2.89% to +2.36% over a 25-year period, with an average rate of approximately zero. The periods having negative real interest rates coincide with periods which had a low inflation rate at the time the bond was issued, with inflation increasing rapidly over the life of the bond. The period having the high positive interest rate corresponds to a situation in which inflation was higher at the time the bond was issued than over the life of the bond.

Table Q.16 Interest Rates, Inflation Rates, and Real Interest Rates*

Year	Long-Term Government Bond Rates (1+r)	Change in Consumer Price Index (1+i)	Imputed Real Interest Rates (1+I)
1951	1.0257	1.079	.9506
1952	1.0268	1.022	1.0047
1953	1.0294	1.008	1.0212
1954	1.0255	1.005	1.0204
1955	1.0284	.996	1.0325
1956	1.0308	1.015	1.0156
1957	1.0347	1.036	.9987
1958	1.0343	1.027	1.0071
1959	1.0407	1.008	1.0324
1960	1.0401	1.016	1.0237
1961	1.0390	1.010	1.0287
1962	1.0395	1.011	1.0282
1963	1.0400	1.012	1.0277
1964	1.0415	1.013	1.0281
1965	1.0421	1.017	1.0247
1966	1.0466	1.029	1.0171
1967	1.0485	1.029	1.0190
1968	1.0525	1.042	1.0101
1969	1.0610	1.054	1.0066
1970	1.0659	1.059	1.0065
1971	1.0574	1.043	1.0138
1972	1.0563	1.033	1.0226
1973	1.0630	1.062	1.0009
1974	1.0699	1.110	.9639
1975	1.0698	1.091	.9806
1976	1.0678	1.058	1.0093
1977	1.0706	1.065	1.0053
1978	1.0789	1.077	1.0018
1979	1.0874	1.113	.9770
MEAN:1951-79	1.0488	1.039	1.0096
MEAN:1953-73	1.0437	.976	1.0184

*SOURCES: U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 2, (U.S. Government Printing Office, Washington, D.C.), p. 1003, September 1975. Board of Governors of the Federal Reserve System, Federal Reserve Bulletin, March 1975, p. A-30, June 1977, p. A-27. U.S. Department of Labor, Bureau of Labor Statistics, Monthly Labor Review, February 1975, p. 117; February 1977, p. 117.

Table Q.17 Real Interest Rate on 10-Year U.S. Government Securities

Year of Issue	Real Interest Rate*
1943	-2.89
1944	-2.45
1945	-2.34
1946	-2.79
1947	-1.74
1948	- .16
1949	- .04
1950	- .76
1951	- .59
1952	.28
1953	.68
1954	.41
1955	.62
1956	.77
1957	1.32
1958	1.01
1959	1.99
1960	2.36
1961	1.11
1962	1.10
1963	.55
1964	.43
1965	- .38
1966	- .77
1967	-1.14

*Derivation: real interest rate equals nominal interest rate minus the inflation rate divided by 1 plus the inflation rate. This formula is an approximation which somewhat underestimates the real interest rate when the bulk of the inflation occurs in the final years and overestimates when the inflation occurs early in the life of the bond.

Source: Nominal Interest Rates from Moody's Investor Services; Inflation Rates from Economic Report of the President (1977); derivation of real interest rates by IR&T.

IR&T also examined the effect of the time period on determining the real rate of return on a variety of securities. Table Q.18 is reprinted from the IR&T report and illustrates the real rate of return (as calculated from their assumptions) on four securities, as calculated from the years 1960 to 1975, and 1965-1975. As shown, the real interest rate can significantly vary depending on the time period over which it is calculated. IR&T also observes that the use of the period 1965 to 1975 may be historically misleading, and states that other than the Great Depression, it would be difficult to find a 10-year period over which common stocks have performed more poorly than that of 1965 to 1975. IR&T observes that merely changing the years considered to the period 1967 to 1977 would significantly improve the performance of common stocks.

Table Q.18 Real Interest Rates on Various Securities

	1960-1975	1965-1975
Long-Term Government Bonds*	- .17	-1.23
State and Local Bonds**	- .44	-2.12
Corporate Bonds†	.52	- .84
Common Stock††	4.8	-2.01

Derivation: Inflation rate based upon GNP deflator, nominal rates of return as indicated in footnotes below.

*Federal Reserve.
**Standard & Poor's 15 Bonds.
†Moody's Corporate Bond.
††Standard & Poor's Composite (includes dividends and capital gains or losses).

It would be a mistake to project negative interest rates extending over extended periods of time such as 50 to 100 years. As stated by IR&T (Ref. 16):

> Current inflation rates are at historically high levels. It probably would be a mistake to project inflation rates using current inflation rates. Any long-term inflation rate of over 10 percent would undoubtedly lead to reforms in both the tax system and in methods of indexing securities. As a result, it would be meaningless to attempt to calculate the

> effects of 50-year inflation rates of greater than 10 percent even if they should occur. It also may be noted that if long-term inflation rates of greater than 10 percent occur, and no adjustments to the financial system are made, then the repercussions will extend far beyond trust funds for hzardous waste disposal.

On the other hand, it would also be a mistake to project high real interest rates (e.g., above 2%) for long time periods, especially when one considers the potential effect of several years of inflation during the time period of interest.

In the GEIS on Uranium Mill Tailings (NUREG-0706), NRC used a projected real interest rate of one percent (Ref. 15). For their regulations on hazardous waste management, EPA has determined that use of a zero real interest rate would be appropriate (Ref. 17). However, in determining this rate, the effect of trustee fees was considered. For large amounts of money, these fees can average from 0.5% to 1% of the value of the principal. Such fees, however, would not be applicable to a state-operated fund.

In their analysis of costs for decommissioning a reference burial ground, PNL assumed a real interest rate of 2% (Ref. 9). This was based upon their examination of the real rate of return on various securities. PNL states that the average real return relative to the gross national product deflator on 3- to 5-year U. S. Government securities was 1.43% for the period 1961 to 1976. For the period 1963 to 1976, the average real return on AAA corporate bonds was 1.95%. For the period 1953 to 1975, the average expected real return on 9- to 12-month treasury issues relative to expected inflation rates was about 2.2%. These figures were taken from the 1977 Statistical Abstract of the U.S., and from a June 1977 article by Carlson in the American Economic Review (Ref. 9).

Another consideration is that states may be restricted by law in the types of securities which may be invested in. That is, securities offering very high rates of return may not be allowable. One analysis of a public trust fund (no taxes), illustrates this. At a high nominal rate of return of 10%, a low nominal rate of return of 8%, an inflation rate of 8%, and trustee fees of 0.9%, then the real effective rate of return for the trust fund varies from -0.8% (for a low rate of return) to +1% (for a high rate of return) (Ref. 17).

All things considered, a real interest rate of about 1% is used in this environmental impact statement. (At an average inflation rate of 9% and an average interest rate of 10%, the real interest rate is calculated to be 0.92%)

5.2 Closure

As shown in Section 4.0, example closure costs at the reference facility could range from a low of $1 million (assuming relatively little site stabilization work is performed at closure) to a high of about $3 million (assuming a great deal of site stabilization work is performed at closure). These figures are in 1980 dollars and the actual closure costs would increase due to inflation. The closure costs for a specific site, of course, are a function of the site environmental characteristics, the facility design and operating practices, and a number of other factors.

For this appendix, the licensee is assumed to bear the costs of the disposal facility. These costs are assumed to be passed on to the disposal facility customer and are represented by a surcharge ($ per cubic meter of waste) on the waste received at the disposal facility. Monies collected through this surcharge mechanism are assumed to be set aside and invested. For example, if a fixed sum (R) is invested into a sinking fund at the end of each year for 20 years (the operating life of the facility), the money accumulated at the end of this time period should be equal to the closure costs (C_o). The relationship between R and C_o is given by (Ref. 16):

$$R = C_o \frac{i}{(1+i)^{IT_o}-1}, \text{ where}$$

i = the average interest rate over (IT_o) years

IT_o = the operating life of the facility

The total costs to the disposal facility customer due to the surcharge is then 20R.

The closure costs, however, are not the costs calculated in 1980 dollars but the 1980 costs inflated to the time of closure. For example, if closure costs in 1980 dollars are C_{80}, and inflation averages j = 9% over IT_o = 20 years, then the costs of closure at the year 2000 is:

$$C_o = C_{80}\ (1 + j)^{IT_o}$$

$$= C_{80}\ (1.09)^{20}$$

$$= 5.60\ C_{80}.$$

Combining equations, the assumed closure surcharge (CS) may be approximated as:

$$CS = \frac{IT_o}{V_w} \frac{(1+j)^{IT_o} C_{80}\ i}{[(1+i)^{IT_o}-1]}$$

There may be a danger, however, that if the disposal facility were to close prematurely, there may be insufficient funds to effect closure. Therefore, in this appendix the projected costs for closure are assumed to be projected by a financial assurance mechanism obtained by the licensee. There is, of course, a fee for financial assurance mechanisms such as surety bonds or letters of credit. This fee is again assumed to be passed onto the disposal facility customer. The total unit costs ($/m^3$) for this fee (CF) may be approximated as follows:

$$CF = \frac{IT_o}{V_w} C_{80} (1 + j)^{IT_o} f, \text{ where}$$

f = annual fee for assuring the availability of closure funds.

The total unit closure costs (UCC) are then given as

$$UCC = CS + CF$$

$$= \frac{IT_o \ (1+j)^{IT_o} C_{80}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o} - 1]} \right\}$$

In the case of the reference facility, two closure scenarios are presented: a low scenario which illustrates costs associated with a situation in which most of the closure activities are carried out during site operations, and a high scenario which illustrates costs associated with a situation in which more extensive site activities are carried out during closure. In this case, these extensive activities are illustrated by the assumption of a complete site restabilization program. As discussed earlier in Section 4.0, costs (1980 dollars) on the order of $1 million are associated with the low closure scenario, while costs on the order of $3 million are associated with the high closure scenario.

Assuming that the average inflation rate is 9%, the average interest rate is 10% and the disposal facility is operated for 20 years, than the closure surcharge for the low closure scenario is about $1.96/m^3$ ($0.06/ft^3$). The closure surcharge for the high closure scenario is about $5.87/m^3$ ($0.17/ft^3$). Similarly, assuming an effective security bond cost of 1.5%, total costs of a surety mechanism over 20 years would total approximately $1.68 million for the low scenario and/or approximately $5.04 million for the high scenario, assuming an average inflation rate of 9%. This corresponds to unit surety fee costs of $1.68/m^3$ ($0.05/ft^3$) or $5.04/m^3$ ($0.14/ft^3$), respectively. These costs would be passed on to the disposal facility customer. It is apparent that disposal facility operating practices in which a low level of activities is required during facility closure would tend to reduce costs to the facility customer.

A low planned level of effort at site closure also helps to provide greater assurance that sufficient funds will be available for closure. This involves less risk to the site owner, and also to the disposal facility operator. This practice also provides greater assurance that the site is in a stable condition prior to license termination. By incorporating disposal facility operating practices whereby efforts are made to place the facility into a stable condition as the site is operated, several years of observation will be available to assess overall site stability. On the other hand, if an extensive restabilization program is implemented during closure, then there would be less assurance that the facility is in a stable condition prior to license termination.

5.3 Institutional Control

Institutional control costs are calculated assuming that money is collected as a surcharge on waste received at the facility and deposited in a state-operated sinking fund. As discussed earlier, for each level of institutional control (high, moderate, and low), costs are divided into 3 time periods: zero to 10 years, 11 to 25 years, and 26 to 100 years. Estimated base costs in 1980 dollars for these time periods for each of the three levels considered are presented in Table 11. As discussed earlier, there are also contingency costs which could be added to the base costs. These contingency costs are a function of assumed site-specific conditions and are applied over the first (0-10 years) time period when a high level of maintenance is most expected.

To calculate the present value of the 100-year institutional control costs in 1980 dollars, the following equation is used (Ref. 10):

$$PV_{80} = C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n} \text{, where}$$

i = nominal interest rate

j = inflation rate

C_a = average annual institutional control costs over the first ten years.

C_b = average annual institutional control costs over years 11 to 25.

C_c = average annual institutional control costs over years 26 to 100.

Under the assumption of a high level of maintenance activities,

$C_a = C_a(\text{base}) + C_a(\text{contingency})$, where $C_a(\text{contingency})$ is a function of site specific conditions and is estimated based upon the degree of potential water accumulation problems at the disposal facility.

As stated above, PV_{80} is in 1980 dollars. However, institutional control does not start until after the site is closed. Therefore, PV_{80} should be inflated by a factor $(1+j)^m$, where m is the time period between the time the facility opens and the time the closure period is ended. That is, $m = IT_o + IT_c$, where IT_o is the period of operation and IT_c is the period of closure. Assuming an operating period of 20 years and a closure period of 2 years, then in this case m = 22 years. Therefore, the amount that must be accumulated in the sinking fund to pay for institutional control costs is:

$$(1+j)^m \, PV_{80}$$

During the operating life of the site (IT_o years), funds are placed into the sinking fund at a rate of R dollars per year, which is obtained as a surcharge on waste delivered to the site during the operating period. During the closure period, no waste is received and so no surcharge is collected. However, interest is still being accrued upon the funds deposited into the sinking fund. To a first approximation, therefore:

$$PV_{80}\,(1+j)^m = \frac{R \quad (1+i)^{TI_o}-1}{i}\,(1+i)^{IT_c}$$

The total amount of money that must be deposited into the sinking fund is therefore 20R. Dividing 20R by the volume of waste received at the site over 20 years (this is one million m^3 of waste for the reference case) gives the unit long-term care costs in dollars per unit volume of waste. Adding the unit capital costs, operational costs, closure costs and institutional control costs gives the total unit disposal costs.

Combining the above terms, the unit institutional control cost (LTC) is equal to:

$$LTC = \frac{IT_o}{V_w}\,\frac{PV_{80}\,(1+j)^m\, i}{[(1+i)^{IT_o}-1]\,(1+i)^{IT_c}} \quad \text{,where}$$

$$PV_{80} = C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n} \text{, where}$$

$m = IT_o + IT_c$, and.

V_w = the total volume of waste delivered to the disposal facility.

An example of institutional control costs can be calculated for the reference facility. For the purposes of this calculation, the following assumptions are made:

$i = 10\%$;
$j = 9\%$;
$IT_o = 20$ years; and
$IT_c = 2$ years

Assuming a high level of institutional control costs and a moderate contingency level,

$C_a = \$439,700 + 367,020 = 806,720$
$C_b = \$302,300$
$C_c = \$149,600$; then
$LTC = \$\ 34.6$ million.

This corresponds to a unit institutional control cost of $\$34.6/m^3$ ($\$0.98/ft^3$).

However, if through improvements in waste form and packaging, as well as improvements in facility design and operation, a low level of institutional control was required, then the costs would total approximately $8.5 million. This corresponds to a unit institutional control cost of $\$8.50/\ m^3$ ($\$0.24/ft^3$).

For this example, the difference between institutional control costs between a stable and an unstable site is therefore on the order of $\$0.74/ft^3$. Assuming that these costs are passed on to the customer, then any efforts to improve the stability of the disposal facility at least up to $\$0.74/ft^3$ would tend to have an overall reduction in costs to a disposal facility customer. A more important consideration, is the relative magnitude of the estimated long-term costs--i.e., $34.6 million vs $8.5 million. There is a hazard that if the disposal facility closes earlier than expected, then sufficient funds may not have been accumulated to provide for all long-term care activities. This can result in a burden to future generations. Obviously, there is a much greater risk of long-term burden if the facility is in an unstable condition rather than a stable condition.

6. SUMMARY

The preceeding sections presented some assumptions and calculational procedures which may be used in this environmental impact statement to determine costs for siting, designing, constructing, operating, and closing a radioactive waste disposal facility, as well as costs for 100 years of long-term care. The costs are calculated in three segments:

1. Capital costs, which include costs associated with siting, designing, licensing, and initial construction of the facility.

2. Operational costs, which include costs associated with receipt and disposal of waste, as well as construction of disposal cells.

3. Postoperational costs, which include costs for (a) facility closure, and (b) institutional control by a site owner.

To calculate total capital and total operational costs, "direct" capital and operational costs are first estimated. These costs are then each multiplied by parameters which account for additional indirect costs, cost of money, contingency and profit.

Postoperational costs are broken up into closure costs and institutional control costs. Closure costs are calculated assuming that adequate funds for closure are provided for by the licensee through use of an investment fund (represented as a surcharge on received waste). The availability of funds for closure is assured by a mechanism such as a surety bond. As discussed in Appendix K, there are a number of mechanisms which could be used to provide adequate assurance for site closure. The costs associated with these mechanisms are expected to be in the neighborhood of one to two percent of the principal. Institutional control costs are calculated based on the assumption that a state-operated sinking fund is established and that a surcharge is levied upon the waste received at the disposal facility on a cost per waste volume arrangement.

Total unit disposal costs (UDC) are therefore calculated as:

$$UDC = UDC_c + UDC_o + UDC_p$$

UDC_c = capital unit disposal costs

$= 10.38$ (direct capital costs)$/V_w$

UDC_o = operational unit disposal costs

$= 1.56$ (direct operational costs)$/V_w$

UDC_p = postoperational unit costs

= (closure costs + institutional control costs)$/V_w$.

$$= \frac{IT_o \quad (1+j)^{IT_o} C_{80}}{V_w} \left\{ f + \frac{i}{[(1+i)^{IT_o}-1]} \right\} + \frac{IT_o \; PV_{80} \; (1+j)^m}{V_{w[(1+i)^{IT_o}-1)]} \; (1+i)^{IT_o}}$$

V_w = Volume of waste received over IT_o years (in m³ or ft³)

IT_o = site operational life (years)

IT_c = closure period (years)

$m = ITo + ITc$

C_{80} = closure costs (1980 dollars)

i = nominal interest rate (expressed as a decimal - e.g., 9% = 0.09)

j = inflation rate (expressed as a decimal)

f = annual fee for assuring availability of closure funds (expected to be a few percent per year and expressed as a decimal).

PV_{80} = present value of institutional control costs in 1980 dollars

$$= C_a \sum_{n=1}^{10} \frac{(1+j)^n}{(1+i)^n} + C_b \sum_{n=11}^{25} \frac{(1+j)^n}{(1+i)^n} + C_c \sum_{n=26}^{100} \frac{(1+j)^n}{(1+i)^n}$$

C_a = average annual costs over first 10 years (1980 dollars)

$= C_a(\text{base}) + C_a(\text{contingency})$

C_b = average annual costs over years 11 to 25 (1980 dollars)

C_c = average annual costs over years 26 to 100 (1980 dollars).

For the purposes of this environmental impact statement, contingency costs are optional but when implemented are assumed to occur when a high level of maintenance is assumed to be required at the site. These costs are assumed to occur during the first 10 years of the institutional control period and are a function of site specific conditions. For the purposes of this impact statement, 3 types of contingency actions are estimated:

1. For sites having very permeable soils, a complete site restabilization program.

2. For sites having moderately permeable soils, a moderate water accumulation problem (25,000 gallons per year) plus a complete site restabilization program.

3. For sites having very impermeable soils, an extensive water accumulation problem (one million gallons of contaminated liquid processed per year) plus a complete site restabilization program.

The above equation which determines unit disposal costs is used in this environmental impact statement to help estimate costs of a number of alternatives for management of radioactive waste. Appendix E contains a summary of the unit disposal costs for the reference facility. Appendix F analyzes the effect of options on disposal facility design and operation on unit capital and unit operational costs.

REFERENCES

1. U.S. Department of Energy, Technology for Commercial Radioactive Waste Management, DOE/ET-0028, May 1979.

2. Sears, M. B., et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle - Conversion of Yellow Cake to Uranium Hexafluoride Part I. The Fluorination - Fractionation Process, ORNL/NUREG/TM-7, September 1977.

3. U.S. Nuclear Regulatory Commission, Final Environmental Statement Concerning Proposed Rulemaking Action: Numerical Guides for Design Objectives of and Limiting Conditions for Operation to Meet the Criterion "As Low As Practicable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents, WASH-1258, July 1973.

4. McGraw-Hill, 1980 Dodge Manual for Building Construction Pricing and Scheduling, Annual Edition, November 15, 1979.

5. McGraw-Hill, 1980 Dodge Guide to Public Works and Heavy Construction Costs, Annual Edition, November 12, 1979.

6. Chem-Nuclear Systems, Inc., Preliminary Site Stabilization and Closure Plan for the Barnwell Low-Level Radioactive Waste Disposal Facility, Docket No. 27-47, May 1980.

7. Title 10, U.S. Code of Federal Regulations, Part 170 (10 CFR 170).

8. U.S. Department of Energy, Understanding Low-Level Radioactive Waste, LLW MP-2, November 1980.

9. Murphy, E. S., G. M. Holter, Technology, Safety, and Costs of Decommissioning a Referenced Low-Level Waste Burial Ground, NUREG/CR-0570, June 1980.

10. Picazo, E., J. Clancy, M. Cody, Specifications for Evaporator Concentrate Solidification at the Maxey Flats Low-Level Radioactive Waste Disposal Site, Task 1.1 Report, Dames & Moore, April 2, 1981.

11. Personal communication, J. Clancy, Dames & Moore, to G. W. Roles, U.S. Nuclear Regulatory Commission, Division of Waste Management, March 4, 1981.

12. Wild, R. G., J. Clancy, M. Ziskin, Water and Sludge Management Alternatives for the Maxey Flats Low Level Waste Disposal Site, Task 2 Report, Dames & Moore, March 1980.

13. Clancy, et al., Evaluation of Alternatives for the Future of Facilities at the Western New York Nuclear Service Center, Dames & Moore, 1978.

14. Sesonske, A., Nuclear Power Plant Design Analysis, TID-26241, 1973.

15. U.S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Uranium Milling, NUREG-0706, September 1980.

16. Burt, R. E., et al., Draft Final Report: An Analysis of Methods for Ensuring Continuity of Operation for Hazardous Waste Disposal Sites, IRT-21600, International Research and Technology Corporation (IR&T) for EPA, April 30, 1980.

17. U.S. EPA, Background Document for Hazardous Waste Disposal Regulations: Availability and Cost of Third-Party Liability Insurance for Permitted Hazardous Waste Disposal Sites, February 20, 1980.

NRC FORM 335
(7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG-0782, Vol. 4

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Draft Environmental Impact Statement on 10 CFR Part 61: "Licensing Requirements for Land Disposal of Radioactive Waste", Appendices G-Q

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
NRC Staff

5. DATE REPORT COMPLETED
MONTH Sept. YEAR 1981

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Low-Level Waste Licensing Branch, Division of Waste Management, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, DC 20555

DATE REPORT ISSUED
MONTH Sept. YEAR 1981

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Same as 9.

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.

13. TYPE OF REPORT
Draft Environmental Impact Statement

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*
The four volume draft environmental impact statement (DEIS) is prepared to guide and support publication of a proposed new regulation, 10 CFR Part 61, for the land disposal of low-level radioactive waste. The analysis in the DEIS include a systematic analysis of a broad range of alternatives relating to the form and content of waste, the engineering design of disposal facilities, the method of operation of the facilities, institutional controls, financial assurances, and administrative and procedural requirements. From the analysis, four main performance objectives are established in the proposed regulation relating to (1) minimizing long-term social commitment and costs, (2) minimizing long-term environmental releases, (3) minimizing long-term impacts to humans potentially inadvertently intruding into disposed waste, and (4) assuring short-term operational safety. Based upon the analysis and overall performance objectives, a number of technical, financial, procedural, and administrative requirements are also developed.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
groundwater migration
inadvertent intrusion
10 CFR Part 61
waste form
financial assurances
institutional controls
radioactive waste
disposal technologies
cost-benefit analysis

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
425

22. PRICE
$

NRC FORM 335 (7-77)

*U.S. GOVERNMENT PRINTING OFFICE: 1981-361-297/1455 1-3

Printed on recycled paper

Federal Recycling Program

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

NUREG-0782, Vol. 4
APP. G-Q

DEIS ON 10 CFR PART 61 "LICENSING REQUIREMENTS FOR LAND DISPOSAL OF RADIOACTIVE WASTE"

SEPTEMBER 1981