NUREG-1853

History and Framework of Commercial Low-Level Radioactive Waste Management in the United States

ACNW White Paper

Advisory Committee on Nuclear Waste
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

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History and Framework of Commercial Low-Level Radioactive Waste Management in the United States

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ABSTRACT

The Advisory Committee on Nuclear Waste (ACNW or the Committee) examined issues associated with management and the disposal of commercial low-level radioactive waste (LLW). As a first step in that examination, the Committee developed this background document, or White Paper, that includes a review of the literature. This LLW White Paper is organized into three parts. Part I provides a historic perspective of past programs for the management and disposal of commercial LLW. Part II describes the U.S. Nuclear Regulatory Commission's commercial LLW regulatory framework found at Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations*. Part III summarizes past ACNW advice in this area, as well as advice provided previously by the Advisory Committee on Reactor Safety before the establishment of the ACNW in 1988. This LLW White Paper also includes six appendices which, among other things, describe the Department of Energy's approach to the management of Government-owned LLW and the regulatory evolution of the "LLW" definition. The White Paper also identifies several emerging staff initiatives, as well as other ongoing initiatives by outside organizations and agencies that could have a bearing on the management of commercial LLW.

FOREWORD

In conjunction with the issuance of this White Paper, the Advisory Committee on Nuclear Waste (the ACNW or the Committee) held a Working Group Meeting during its 170th meeting in May 2006. The purposes of the 2006 Working Group Meeting were to obtain current information on commercial low-level radioactive waste (LLW) management practices and identify emerging low-level radioactive waste management issues and concerns. The Committee also solicited industry and stakeholder views regarding the future U.S. Nuclear Regulatory Commission (NRC) role in the area of commercial LLW management to ensure a stable, reliable, and adaptable regulatory framework for effective management of those wastes. The NRC staff recently noted that it is updating its strategic planning in the LLW area following Commission-directed reduction in the program about a decade ago. Consequently, as part of the Working Group Meeting, the Committee solicited stakeholder views on what changes to the regulatory framework for managing LLW should be recommended for Commission consideration as well as to identify specific impacts, both positive and negative, of potential future staff activities.

The May 2006 meeting followed from the ACNW's March 2005 briefing of the Commission. The Working Group Meeting was divided into four-sessions covering the following themes:

- Current LLW program status;
- Existing regulatory framework for managing commercial LLW and operational issues;
- Industry panel discussion on current and future challenges in the management of LLW; and
- Stakeholder perspectives on the forthcoming NRC strategic assessment effort.

The ACNW two-day Working Group Meeting drew an attendance of approximately 100 individuals. Formal participation in the meeting included representatives of the American Ecology Corporation, the Army Corps of Engineers, EnergySolutions (formerly Envirocare), the California Radiation (CalRad) Forum, Duratek-Chem-Nuclear Systems, LLC, EnergySolutions, the Entergy utilities group, the environmental community, Harvard University, the LLW Forum, the Nuclear Energy Institute, the South Carolina Department of Health and Environmental Control, the Southwestern LLW Compact, the Texas Commission on Environmental Quality, and Waste Control Specialists, LLC. Staff from NRC's Division of Waste Management and Environmental Protection, and independent stakeholders, also participated in the discussions.

Participants and stakeholders from the Working Group Meeting offered several observations for the ACNW to consider. Stakeholders were also invited to comment on the December 2005 version of the ACNW White Paper before it was finalized; none were received. The Committee subsequently developed a letter report to Commission addressing stated purposes of the Working Group Meeting. See Ryan (2006). The Committee also intends to comment on the results of the NRC strategic planning effort in the area of commercial LLW management. See NRC (2006c).

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EXECUTIVE SUMMARY

At a 2005 briefing of the U.S. Nuclear Regulatory Commission (NRC or the Commission), the Advisory Committee on Nuclear Waste (ACNW or the Committee) agreed to examine some of the issues related to the management of commercial low-level radioactive waste (LLW). As a first step, the Committee developed a background paper or White Paper that briefly examines the history and current status of commercial LLW disposal in the United States, as well as the reasoning and approach used by the NRC staff to develop its LLW regulations in Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61).

The ACNW transmitted a preliminary version of this White Paper to the Commission on December 27, 2005, following the ACNW's 166th meeting. See Ryan (2005). The paper subsequently underwent an editorial review, as well as a limited external peer review. Although some minor modifications and revisions to the White Paper have been made as a result of those reviews, the final report contained herein remains substantially unchanged from that first transmitted to the Commission in December 2005. However, there are three key enhancements. First, the revised report includes an expanded discussion concerning low-activity radioactive wastes. This discussion reviews the NRC's earlier *de minimis* regulatory position and the subsequent Below Regulatory Concern Policy Statements. Second, ACNW staff identified additional letters prepared by the Advisory Committee on Reactor Safety (ACRS), the ACNW's predecessor, which have now been included in the discussion of past Advisory Committee reviews of the NRC LLW program found in Part III of this report. Lastly, for the purposes of comparison, Appendix A includes a summary describing how the U.S. Department of Energy (DOE) manages LLW generated from former Government programs.

It should be noted that preparation of this White Paper is also intended to satisfy an NRC goal of knowledge management.

Structure of the ACNW LLW White Paper

The ACNW White Paper provides an abridged examination of the NRC's LLW regulatory program based on a review of key literature sources.[1] It also includes a summary of past ACNW advice in the LLW area, including the advice of the ACRS. Other areas of information potentially bearing on this review were not examined because of time constraints or other ongoing reviews. These areas include an examination of international approaches to the management of commercial LLW (i.e., OECD Nuclear Energy Agency, 2005) and domestic approaches to the management of chemically hazardous waste mixed with radioactive constituents.

The White Paper is organized into three parts.

Part I. Part I is a history of the national LLW program. This history reviews early approaches to the management of commercial LLW by the then Atomic Energy Commission (AEC) and summarizes Congressional actions following the poor performance of the first AEC LLW disposal sites. These actions include the NRC's efforts

[1]Many organizations and entities have written on assorted issues related to the management of LLW in the United States and, as a result, a rich body of literature exists. Thus, the authors faced the challenge of identifying those key references that would best describe this history. It should be recognized therefore that other researchers may reach different conclusions as to which references are most appropriate to cite in a review of this type.

in the late 1970s to early 1980s to develop LLW disposal regulations currently found in 10 CFR Part 61. Following Congressional passage of the Low-Level Waste Policy Act of 1980 (LLWPA) and the Low-Level Waste Policy Amendments Act of 1985 (LLWPAA), the White Paper tracks state efforts to site new LLW disposal facilities following the establishment of the LLW Interstate Compact system. Part I concludes with a current status of the national program, which includes recent efforts by the states to site new disposal facilities.

Several stakeholder organizations have prepared position papers expressing their views on various matters related to the management of commercial LLW. Some of these position papers also call for regulatory changes to the NRC's LLW regulatory framework. The White Paper identifies those organizations with published positions on the issues, but does not attempt to summarize their respective positions.

Part II. Part II is dedicated primarily to the NRC's LLW regulatory framework found at 10 CFR Part 61. The purpose of this section is to provide some general background on the staff's approach to developing the regulation and, in doing so, highlight the key issues it considered in the development of the LLW rule. The literature indicates that the Commission's intent in promulgating 10 CFR Part 61 was to develop a comprehensive regulation that addressed all phases of the LLW disposal cycle. This meant that the regulation had to be sufficient to cover disposal operations and closure, as well as the long-term period of waste isolation. The Commission was also concerned about the potential for inadvertent human intrusion once institutional control of the site had ended and societal knowledge of the hazard ceased. In relying on near-surface disposal, the possibility exists for exposures to ionizing radiation resulting from man's efforts to reclaim a disposal site for productive use, such as farming, housing, or natural resource development. It was therefore recognized early in the 10 CFR Part 61 scoping process that because these types of behavior could not be predicted, it was impossible to guarantee that inadvertent human intrusion at the site would not occur in the future. Consequently, the Commission determined that future generations, in effect, should be afforded the same level of protection as the general population today.

NUREG-0782, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," issued September 1981, and NUREG-0945, "Final Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," issued November 1982, provide a detailed account of the LLW regulation development process and the disposition of key issues. These two documents indicate that, in developing 10 CFR Part 61, the staff gave considerable attention to determining who should be protected and what the level of protection should be. The literature also indicates that radiation protection standards for commercial LLW did not exist at the time. Part II reviews the U.S. Environmental Protection Agency's (EPA) efforts to promulgate LLW standards and the NRC approach to the selection of a default LLW dose criteria to support development of its regulation in the absence of those standards. Part II also reviews the 10 CFR Part 61 waste classification system that evolved from these scoping efforts and forms the basis for the LLW rule today, as well as DOE efforts to manage commercial greater-than-Class C LLW. The section concludes with an overview of the NRC staff's past and current LLW program activities that are not associated with the development of the 10 CFR Part 61 regulation.

Part III. The ACNW did not exist at the time the NRC's LLW regulatory framework in 10 CFR Part 61 was created. The ACRS, however, had established a subcommittee that monitored developments in the waste management area.

Together, both Committees have issued more than 40 letter reports commenting on various aspects of this framework. Part III of the White Paper summarizes this past advice. The principal observations presented in past NRC Advisory Committee letters can be generally classified into the following six areas, with the corresponding number of letters:[2]

- general LLW management issues - *12 letters*
- NRC LLW regulatory framework - *19 letters*
- ground-water monitoring - *3 letters*
- chemically mixed radioactive waste - *3 letters*
- performance assessment - *7 letters*
- waste package and waste form - *3 letters*

Appendices. This LLW White Paper also includes the following appendices containing useful background information to refer to when reading the main body of the White Paper:

- a review of the DOE approach to the management of Government-owned LLW
- a review of the evolution of the regulatory definition of commercial LLW
- a summary of the structure of the NRC's LLW disposal regulation in 10 CFR Part 61
- a summary of the NRC staff's recommendations for the conduct of a LLW performance assessment found in NUREG-1573, "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities - Recommendations of NRC's Performance Assessment Working Group," issued October 2000, which are consistent with the performance objectives identified in Subpart C of 10 CFR Part 61
- a selected bibliography of LLW technical reports sponsored by the NRC Office of Nuclear Regulatory Research since the publication of NUREG-1573
- the Commission's 1995 policy statement on the use of probabilistic risk assessment methods in nuclear regulatory activities

Emerging LLW Issues

Based on discussions with the NRC staff at its 165th meeting in November 2005, the Committee became aware of a number of emerging staff LLW initiatives, as well as other ongoing initiatives by outside organizations and agencies that could have a bearing on the management of commercial LLW. The White Paper references these additional efforts and reviews. For example, the staff is updating its strategic planning in the LLW area following a Commission-directed reduction in the program about 10 years ago. In addition, the staff is taking the following actions:

- reviewing past guidance on LLW storage
- responding to a 2005 Commission order regarding the disposal of large quantities of depleted uranium
- addressing 10 CFR Part 20.2002, "Method for Obtaining Approval of Proposed Disposal Procedures," exemption issues

Besides the staff's internal efforts, a number of external efforts and initiatives are underway that may have a bearing on the future of commercial LLW management, including the following:

[2]Some letters address multiple topics.

- the recently-completed National Academy of Sciences low-activity radioactive waste study (National Research Council, 2006)
- a new U.S. Government Accountability Office (2005) review of best LLW management practices
- the ongoing EPA (2003) advance notice of proposed rulemaking on low-activity radioactive waste

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These individuals do not necessarily approve, disapprove, or endorse the views expressed in this report.

ABBREVIATIONS

ACNW	Advisory Committee on Nuclear Waste
ACRS	Advisory Committee on Reactor Safety
AEA	Atomic Energy Act of 1954
AEC	Atomic Energy Commission
AGV	above-ground vault
AIF	assured isolation facility
ALARA	as low as reasonably achievable
ANPR	advance notice of proposed rulemaking
BEIR	biological effects of ionizing radiation
BLM	Bureau of Land Management
BRC	below regulatory concern
BWR	boiling-water reactor
CAA	Clean Air Act of 1977, as amended
CDPHE	Colorado Department of Public Health and Environment
CEQ	Council on Environmental Quality
CFR	*Code of Federal Regulations*
Ci	curie
CORAR	Council on Radionuclides and Radiopharmaceuticals
CRCPD	Conference of Radiation Control Program Directors
d	day
DCG	disposal concentration guide
DEIS	draft environmental impact statement
DNFSB	Defense Nuclear Facilities Safety Board
DOI	U.S. Department of Interior
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSI	direction-setting issue
EMCB	earth-mounded concrete bunker
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
FEIS	final environmental impact statement
FFCA	Federal Facility Compliance Act of 1992
FR	*Federal Register*
FRC	Federal Radiation Council
ft^3	cubic feet
GAO	U.S. General Accounting Office (before July 2004); U.S. Government Accountability Office (after July 2004)
GEIS	generic environmental impact statement
GTCC	greater-than-Class C (radioactive waste)

HIC	high-integrity container
HLW	high-level radioactive waste
HDPE	high-density polyethylene
hr	hour
ICRP	International Commission on Radiation Protection
ISFSI	independent spent fuel storage installation
LAW	low-activity radioactive waste
LFRG	LLW Disposal Facility Federal Review Group (of DOE)
LLW	low-level radioactive waste
LLW Forum	Low-Level Radioactive Waste Forum
LLWPA	Low-Level Waste Policy Act of 1980
LLWPAA	Low-Level Waste Policy Amendments Act of 1985
LSV	liquid scintillation vial
LWR	light-water reactor
$\mu Ci/cm^3$	microcurie per cubic centimeter
$\mu g/L$	microgram per liter
m^3	cubic meter
MAC	maximum average concentration
MCL	maximum concentration limit
MIMS	Manifest Information Management System (of DOE)
MLLW	mixed low-level radioactive waste
MOU	memorandum of understanding
MOX	mixed-oxide (fuel)
mrem/yr	millirem per year
MRS	monitored retrievable storage
nCi/g	nanocurie per gram
NACOA	National Advisory Committee on Oceans and the Atmosphere
NARM	naturally occurring or accelerator-produced radioactive material
NAS	National Academy of Sciences
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act of 1970
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NFS	Nuclear Fuel Services, Inc.
NMSS	Office of Nuclear Materials Safety and Safeguards
NOI	notice of inquiry
NORM	naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment
pCi/g	picocurie per gram
pCi/L	picocurie per liter
PAM	performance assessment methodology (for LLW)
PCB	polychlorinated biphenyl

PNL	Pacific Northwest Laboratory
PRA	probabilistic risk assessment
PRESTO	Protection of Radiation Effects from Shallow Trench Operations (EPA computer code)
psi	pounds per square inch
PWR	pressurized-water reactor
QA	quality assurance
R&D	research and development
RCRA	Resource Conservation and Recovery Act of 1976
RES	Office of Nuclear Regulatory Research
s	second
SA	specific activity
SLB	shallow land burial
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SRM	staff requirements memorandum
SS	source and special nuclear material
TCEQ	Texas Commission on Environmental Quality
TEDE	total effective dose equivalent
TENR	technologically enhanced natural radiation
TENORM	technologically-enhanced naturally occurring radioactive materials
TRU	transuranic (radioactive waste)
USGS	U.S. Geological Survey
WCS	Waste Control Specialists, LLC (of Texas)
WIPP	Waste Isolation Pilot Plant
yr	year

PART I. LOW-LEVEL RADIOACTIVE WASTE PROGRAM HISTORY

1 INTRODUCTION

Most establishments working with radioactive materials produce radioactive wastes, since radioactive material contaminates anything with which it comes into contact. In the United States, thousands of establishments, both government and private, are licensed to use radioactive materials.[1] The volume and level of activity in the wastes produced varies in direct proportion to the amount of radioactive material used. Historically, the greatest proportion of radioactive waste produced domestically is low-level radioactive waste (LLW), although LLW only accounts for about 0.1 percent of the total radioactivity being disposed (Moeller, 1992, p. 118).

The term "low-level radioactive waste" or "LLW" has carried a changing meaning over the years. At the time the U.S. Nuclear Regulatory Commission (NRC or the Commission) promulgated the LLW disposal regulations found at Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61), the term LLW was exclusionary. It generally meant that portion of the radioactive waste stream that did not fit the prevailing definition of high-level radioactive waste (HLW) or intermediate-level radioactive waste, with concentrations of transuranic (TRU) elements less than 100 nanocuries per gram (nCi/g). Some LLW has radioactive material concentrations comparable to that of spent nuclear fuel (SNF), and the NRC considers this waste to be greater-than-Class C GTCC) LLW.The U.S. Department of Energy (DOE) is responsible for managing such wastes.

[1]The Nuclear Energy Agency (1998) provides an overview of the beneficial use of radioactive materials.

LLW is currently defined at 10 CFR Part 61 in the same way that it is defined in the Low-Level Waste Policy Act of 1980 (LLWPA - Public Law 96-573) and the Nuclear Waste Policy Act of 1982, as amended - specifically, radioactive waste that is not classified as HLW, TRU waste, SNF, or byproduct material as defined in Section 11e.(2) of the Atomic Energy Act of 1954 (AEA - i.e., uranium or thorium tailings and waste).

1.1 Commercial LLW

LLW typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipments and tools, luminous dials, swabs, injection needles, syringes, and laboratory animal carcasses and tissues (see Table 1). The radioactive material concentration can range from just above background levels found in nature to, in certain cases, very high concentrations of radioactive material, such as parts from the inside of a nuclear power plant reactor vessel. About 97 percent of LLW decays to safe levels within 100 years, although a small percentage of longer lived radionuclides persist at potentially hazardous concentrations for thousands of years or more. Licensees typically store LLW on site, either until it has decayed and can be disposed as ordinary (municipal) trash or until amounts are large enough for shipment to an approved LLW disposal site. The NRC has historically discouraged the use of onsite storage of LLW as a substitute for permanent disposal (NRC, 1996a, p. 6-44).[2]

[2]In Generic Letter 81-38 (NRC, 1981e), the NRC staff first noted that no nuclear facility should be built to store waste for longer than 5 years under a licensee's 10 CFR 50.59, "Changes, Tests and Experiments," evaluation. The licensee should obtain specific NRC approval. This limitation was based in part on safety considerations, but was aimed at encouraging the

The NRC classifies commercial LLW as Class A, B, or C (see Table 2). Key decision parameters in this classification system are the physical stability of the waste form and packaging and its radioisotopic concentration. In any year, the amount of commercial LLW generated can vary. Generally, it is on the order of 10^6 cubic feet (ft^3) or about 28,000 cubic meters (m^3). In 2004, about 3.8×10^6 ft^3 of LLW was generated, representing about 3.4×10^5 curies (Ci) of radioactivity. The majority of the volume (more than 99 percent) was Class A LLW. Although Class A LLW is the greatest in terms of volume of material generated, Class C wastes contain most of the activity - averaging between 69 and 97 percent of all of the curies disposed of over the last ten years.[3]

Technological advances, as well as major reductions in the extent of contaminated areas within power plants, have contributed to the decrease in waste quantities generated over the past several decades. However, the volume of material being disposed has recently increased as a result of the decommissioning of the first generation of commercial nuclear power plants (Buckley, 2005). Utilities have undertaken volume reduction and waste minimization efforts in response to increased disposal costs for LLW. These efforts include segregation, decontamination, minimizing exposure of materials and tools to the contaminated environment, sorting potential contaminated materials, and dewatering and evaporation. See Strauss (1987), Coley (1987), and Electric Power Research Institute (EPRI - 1988a, 1988b). Some of the most effective volume reduction strategies are compacting, consolidating, and monitoring waste streams to reduce the volume of LLW requiring storage and to reduce the exposure of routine equipment to the reactor environment. See, for example, Strauss (1987), Taylor (1987), EPRI (1988a, 1988b, 1988c), and Shaw (1988). Based on their economic model, Voth and Witzig (1986) note that waste generators have achieved most of the waste volume reductions in the past in unsited LLW disposal site regions.

In anticipation of receiving license applications for the renewal of operating licenses for nuclear power plants, the Commission published a generic EIS (GEIS) in 1996. In conjunction with the GEIS, the Commission examined the volume of LLW that would be generated as a result of power plant refurbishments necessary to support a 20-year license extension. Although additional (non-routine) volumes of LLW would be generated as part of any refurbishment process, the Commission concluded that the radiological and nonradiological impacts would be small. In the matter of the management of those wastes, it was noted in the GEIS that interim storage may have to take place at the reactor sites if (commercial) off-site disposal facilities were unavailable. See NRC (1996b). Should LLW storage extend beyond the 5-year guideline established by the staff (in excess activity or volume limits projected in a power plant license application), EPRI (1992) has suggested that licensees may need to secure additional license authorities under 10 CFR Part 30 ("Rules of General Applicability to Domestic Licensing of Byproduct Material") and/or Part 50 ("Domestic Licensing of Production and Utilization Facilities"). Also see Section 5.2 of this report.

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development of permanent LLW disposal facilities. However, recognizing that the 5-year limit has not influenced the development of new waste disposal facilities and that the states continue to make slow progress, the NRC has eliminated any language in its guidance to suggest that the 5-year term is a limit beyond which storage would not be allowed.

[3]These data are taken from the Manifest Information Management System (MIMS). DOE uses this computerized system to compile information on commercial LLW generation and disposal. The MIMS Web site can be found at *http://mims.apps.em.doe.gov/*.

Table 1 **Commercial LLW Profile.** Adopted from Office of Technology Assessment – OTA (1989, p. 83), citing various sources.

Generator	Waste Forms	Principal Radionuclides		
		Isotope	Half-life ($t_{½}$)	Radiation Type
Nuclear Power Plants	Dry solids, used equipment, sludges, organic solvents and other liquids, water purification filter media and resins, irradiated hardware, gaseous wastes	Co-58	71.3 d	β, γ
		Co-60	5 yr	β, γ
		Cr-51	27.7 yr	β, γ
		Mn-54	312 d	β, γ
		Cs-134	2 yr	β, γ
		Cs-137	30 yr	β, γ
		Ni-59	80,000 yr	β, γ
		H-3	12.3 yr	β
		Zn-65	243 d	β, γ
		I-131	157,000,000 yr	β
Industry	Pharmaceutical	C-14	5730 yr	β
		H-3	12.3 yr	β
		P-32	14.3 d	β
		S-35	87 d	β
		Tc-99	6 hr	γ
	Nuclear Fuel Fabricators	U-235	700,000,000 yr	α, γ
		U-238	4,470,000,000 yr	α, γ
	Sealed Sources *	several	variable	β, γ
Medical and Academia	Dry solids, used equipment, glassware, plastics, scintillation fluids and other organic solvents, animal carcasses, medical treatment and research materials, gaseous wastes	H-3	12.3 yr	β
		C-14	5730 yr	β
		I-125	60.2 d	β, γ
		S-35	87 d	β
		Rb-87	4,900,000,000 yr	β
		Ca-45	163 d	β
		Cr-51	27.7 d	γ
		Tc-99m	6 hr	γ

* Most of the isotopes of interest have half-lives on the order of a few seconds (Kr-81m – 13 seconds) to hours (Y-87 – 80 hours). Thus, they typically decay or can be stored on site until such time that they become innocuous and can be disposed of as part of the municipal waste stream or along with LLW as byproduct material. Co-57, however, is an exception at 271 days. Other exceptions include some longer lived gamma-ray emitters, produced through particle accelerators (Na–22 – 2.6 years) as well as particle accelerator targets and components.

Table 2 **Overview of 10 CFR Part 61 LLW Classes and Waste Characteristics.** Adopted from NRC (1989, p. 9a) and OTA (1989, pp. 83–84). Section 7.4.3 of this report describes the overall 10 CFR Part 61 waste classification process in more detail.

	Radionuclide Concentration	Waste Form	Examples	Intruder Protection*	Waste Segregation
Class A	low concentrations	minimum waste form requirements no stabilization requirements	contaminated protective clothing, paper, trash	no measures to protect intruder waste decays to acceptable levels to intruder after 100 yr	unstable Class A waste must be segregated from Class B and C wastes
Class B	higher concentrations activity generally 10 – 40 times greater than Class A	minimum waste form requirements 300-yr stabilization requirement	resins and filters from nuclear power plants, wastes encapsulated or stabilized in concrete	requires stabilization of waste form to protect intruder waste decays to acceptable levels to intruder after 100 yr, provided that waste form is recognizable	need not be segregated from Class C wastes
Class C	highest concentrations activity generally 10 – 100 times greater than Class B	minimum waste form requirements 300-yr stabilization requirement	nuclear power plant reactor components, sealed sources, high-activity industrial waste	requires stabilization of waste form and deeper disposal (or barriers) to protect intruder waste decays to acceptable levels to intruder after 500 yr	need not be segregated from Class B wastes

* The 10 CFR Part 61 regulation assumes a 100-yr caretaker period.

1.2 Chemically Mixed LLW

Some commercial LLW contains chemically hazardous constituents and is referred to as "mixed waste." Mixed LLW typically includes organic liquids, metallic lead, cadmium, chromates, and waste oils (Bowerman et al., 1985). This type of waste is produced by the full range of LLW generators and waste processors. Various estimates (OTA, 1989, p. 85; Klein et al., 1992, p. xiii; NRC, 1999) suggest that 3 to 10 percent of commercial LLW is chemically mixed waste.

Mixed LLW is also subject to regulation under the Resource Conservation and Recovery Act of 1976 (RCRA). The U.S. Environmental Protection Agency (EPA) administers RCRA, along with states with regulations comparable to RCRA.

Section 1004(5) of RCRA defines a hazardous waste as any substance that is flammable, corrosive, reactive, or toxic. On May 19, 1980, EPA published its final rule defining the general framework for identifying chemically hazardous wastes beginning at page 33084 of Volume 45 of the *Federal Register* (45 FR 33084). The applicable regulations can be found at 40 CFR Part 261, "Identification and Listing of Hazardous Waste." Until 1985, chemically mixed LLW could be disposed of in a facility meeting only the NRC's 10 CFR Part 61 regulations (OTA, 1989, p. 86). Thereafter, the management and disposal of RCRA-classified waste had to comply with EPA regulations as well. As a result of legislative ambiguity (Parler, 1989), both the NRC and EPA regulate the management of chemically mixed radioactive waste. EPA published a final rule in 2001 (66 FR 27218) that conditionally exempted mixed low-activity radioactive waste (LAW) from RCRA regulations during storage, treatment, and disposal. See Section 5.3 of this report. In 2003, EPA published an advance notice of proposed rulemaking (ANPR) requesting comment on the suitability of using RCRA Subtitle-C disposal technology (and regulations) for disposing of certain "unimportant quantities" of mixed LAW. [4] See 68 FR 65120.

The review of mixed LLW issues is beyond the scope of this report. However, other researchers have studied the issue. See, for example, General Research Corporation (1980), Bowerman et al. (1986), Kempf et al. (1986), and OTA (1989).

1.3 Government-Owned LLW

Some LLW is generated in facilities that are not regulated by the Commission's authority under the AEA, but are regulated by NRC Agreement States.[5] DOE, operating under different rules from the commercial sector, also manages and disposes of Government-owned LLW. Government-owned LLW includes waste created from past nuclear weapons production and research, environmental restoration of Federal facilities, and routine operations of the U.S. Navy's nuclear propulsion program.

Although a detailed review of the DOE LLW management program is also beyond the scope of this report, Appendix A offers a brief description of this program and provides an alternative perspective on the management of these wastes. However, unlike commercial LLW, it should be noted that a greater proportion of Government-owned LLW is chemically mixed - estimated to be between 50 and 80 percent - which affects the Department's management strategy for these wastes (National Research Council, 1999, p. 25).

[4] "Unimportant quantities" is a legal term that applies to source material defined in 10 CFR Part 40 ("Domestic Licensing of Source Material"). It refers to uranium- and/or thorium-bearing materials in concentrations less than 0.05 percent by weight that are deferred from regulation.

[5] Under Section 274 of the AEA, the NRC can relinquish portions of its regulatory authority to license and regulate byproduct materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials to the states. The mechanism for the transfer of the NRC's authority is an agreement signed by the Governor of the state and the Chairman of the Commission, in accordance with Section 274b of the act. Agreement States therefore are those states whose Governors have entered into such limited agreements with the Commission.

2 EARLY APPROACHES TO THE MANAGEMENT OF LOW-LEVEL RADIOACTIVE WASTE

In the early years of the domestic nuclear energy industry, the Atomic Energy Commission (AEC) used three methods to dispose of radioactive waste — dilution and dispersion, shallow land burial (SLB), and disposal at sea.[6]

2.1 Ocean Disposal

Initially, only the AEC disposed of both commercial and Government-owned LLW. Commercial wastes were typically disposed in the ocean, based on the recommendations of the National Academy of Sciences (NAS) at the time. See National Research Council (1959, 1962).[7] Because most radionuclides have short half-lives, many believed that dilution in ocean water plus decay would result in innocuous levels of radiation and pose minimal hazards to man. Furthermore, the sea was readily available and economic to use (Raubvogel, 1982, pp. 21-23). The U.S. Navy conducted disposal at sea until about 1959. Thereafter, the AEC licensed seven companies to dispose of the wastes.

Ocean disposal of LLW occurred in waters greater than 1000 fathoms (about 6000 feet) following the 1954 recommendations of the National Bureau of Standards' (NBS) National Committee on Radiation Protection (NBS, 1954, p. 2). The disposal container most often used was a 55-gallon steel drum. The LLW was mixed with cement or concrete to assure sinking and to withstand the deep-sea pressures. Sometimes, prefabricated steel-mesh-concrete boxes of varying sizes were used instead of drums. As was the case with the steel drums, cement or concrete was mixed with the LLW to achieve the negative buoyancy necessary to assure sinking. This general design configuration was not intended to be permanent (U.S. General Accounting Office[8] - GAO, 1981, pp. 2-9). It provided an estimated 10 years of radionuclide containment in the marine environment[9] (National Research Council, 1959, p. 1).

More than 60 LLW disposal sites were distributed between 5 major disposal locations in the Pacific Ocean, 1 in the Gulf of Mexico, and 11 in the Atlantic Ocean. The waste was not evenly distributed among the sites; three sites received about 90 percent of the LLW, by volume. Table 3 summarizes the number of LLW containers and the associated activity disposed. Overall, it is estimated that about 95 percent of the containers disposed in the Atlantic and Pacific Oceans, and the Gulf of Mexico were 55-gallon drums (National Research Council, 1971, p. 36).

In 1970, the AEC ended its practice of disposing of LLW at sea. Sea disposal was discontinued in conformity with U.S. environmental laws and regulations as well as international agreements intended to prevent marine pollution, such as the

[6]The AEA initially assigned the AEC the functions of both encouraging the use of nuclear power and regulating its safety. The AEC regulatory programs sought to ensure public health and safety from the hazards of nuclear power without imposing excessive requirements that would inhibit the growth of the industry.

[7]The NAS generally recommended that no 300-mile section of the coast line should contain more than three disposal areas and that adjacent disposal areas be separated by at least 75 miles. The NAS also had specific recommendations on the total quantity of activity disposed at any one location monthly, as well as annually.

[8]In July 2004, the GAO was renamed the Government Accountability Office.

[9]With the exception of the radionuclides strontium-90, cesium-137, and possibly cobalt-60.

Table 3 **Summary of LLW Ocean Disposal Operations in U.S. Territorial Waters.** Compiled using National Research Council reports published in 1959 (p. 5) and 1971 (p. 37) and Appendix C to a report published in April 1984 on this topic by the National Advisory Committee on Oceans and Atmosphere. However, the reader should note that questions have been raised in the past about the accuracy of past recordkeeping and the accuracy of these statistics (Raubvogel, 1982, p. 23).

Water Body	Years of Disposal Activity	Number of Individual Disposal Sites	Number of Containers	Estimated Activity at Time of Packaging (Ci)
Atlantic Ocean	1951–1967	+24	34,203*	79,482.9
Pacific Ocean	1946–1970	+34	56,261	14,980.5
Gulf of Mexico	< 1959	2	79	< 25

* Includes unpackaged and liquid wastes.

1972 London Convention.[10] The early 1980s saw a renewed interest in sea disposal.

In a report dated April 1984, the National Advisory Committee on Oceans and the Atmosphere (NACOA) recommended that the present policy of excluding the use of the ocean for LLW disposal be reversed (NACOA, 1984, pp. 6–7). These recommendations were never adopted and the practice of ocean dumping was never reinstated in the United States. Consistent with the applicable regulations,[11] any request for ocean disposal of LLW requires a permit that must be approved by both houses of Congress.

2.2 Land Disposal

In the 1960s, commercial interest in ocean disposal began to decline and had ended completely by 1970. One of the principal reasons for the decline was the adverse public reaction to polluting the ocean. The other motivation was economic. Ocean disposal was reported to cost as much as $48.75 per 55-gallon drum compared to $5.15 per drum for burial on land (Mazuzan and Walker, 1997, p. 367). For these reasons, the AEC endorsed a new disposal policy permitting land burial using commercial disposal sites. Under this policy, it was envisioned that the private sector would identify sites with favorable geologic and meteorologic conditions and provide the same disposal service to commercial generators, but at lower cost. The intent was to locate disposal sites in those regions of the country generating the wastes. At the time, the Oak Ridge National Laboratory (ORNL) and the National Reactor Testing Station (now the Idaho National Engineering Laboratory) were the principal handlers of LLW generated by then-AEC licensees. LLW generated there and at other Federal facilities was being disposed at about 16 major and lesser Federally owned sites rather than in the ocean (National Research Council, 1976, pp. 18–19).

[10] Known more formally as the "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972," the London Convention has been in force since 1975. Currently 80 Member states (including the United States) are parties to this convention. In 1996, a protocol was developed to amend the London Convention to ban ocean disposal of radioactive wastes and incineration at sea. See DOE (2005b, pp. 17–18).

[11] The Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 95-532) authorizes EPA to issue permits and promulgate regulations for disposing of materials into United States territorial waters. Those regulations (EPA, 1977a) can be found in 40 CFR Part 220 ("Ocean Dumping").

Because of concerns about the long-term effectiveness of institutional controls at potential disposal sites, in January 1960, the AEC proposed that commercial disposal facilities be located on Government-owned land and regulated and licensed by the Federal Government (Mazuzan and Walker, 1997, p. 366). As a temporary measure, until a commercial disposal capability became available, the AEC decided to accept nongovernment LLW for disposal as part of an "Interim Radioactive Waste Burial Program" (Op cit., p. 367). In September 1962, the AEC authorized private firms to dispose of commercial LLW on land. The first privately operated LLW land-burial service was near Beatty, Nevada, on state-owned land. Nuclear Engineering, Inc., which the AEC had already licensed to commercially dispose of LLW at sea, operated the site. At the time, licensing criteria specific to the disposal of LLW did not exist. The only applicable licensing criteria were the general AEC regulations at 10 CFR 20.302(a), 10 CFR 20.302(b), and 10 CFR 20.304.[12]

In May 1963, the AEC announced its intent to withdraw its interim disposal services for radioactive wastes shipped on or after August 12, 1963, because of the establishment of a commercial disposal alternatives at Beatty and at Maxey Flats (AEC, 1963). Interim disposal services were terminated in November 1963. The AEC also announced its intention to use commercial disposal sites for its wastes, to the extent that it could obtain "fair and reasonable" prices for the service (Lennemann, 1976, p. 268). Although additional disposal sites were later established (see next paragraph), Lennemann (1976, p. 269) notes that at no time did the AEC believe that more than two regional LLW disposal sites were necessary.

By 1971, a total of six shallow-burial LLW disposal facilities were licensed and operated to dispose of the Nation's commercial LLW (see Table 4). Most of these facilities were located within the boundaries of or adjacent to a much larger Federal reservation operated by the AEC. Four of the disposal sites — Beatty, Barnwell, Maxey Flats, and West Valley — were licensed by their respective host states through the Agreement State program with the AEC under Section 274 of the AEA. The AEC licensed the two remaining sites (Richland and Sheffield) because Washington and Illinois had not become Agreement States at the time of licensing.

The commercially operated sites adopted the practice of near-surface, SLB disposal technology adhered to at existing AEC facilities at the time. This disposal method relies on relatively simple engineering designs to isolate wastes from infiltrating groundwater. The natural (geologic) characteristics of the site are the principal attenuators of any radioactive material that might be released to the accessible environment. There were no systematic site selection criteria or design requirements that could be used to establish the best mix of features necessary to contain and isolate the wastes (Robertson, 1984, p. 105). Disposal generally involved clearing and grading the land and excavating shallow unlined trenches - generally less than 50-feet (15-m) deep - that would be used to receive the waste.

At the time, no specific packaging requirements existed for LLW disposal.[13] LLW was packaged in a variety of container types that were randomly dumped or stacked into the trenches. The waste was generally placed into the trenches on a first-come, first-served basis. Trenches were then backfilled using materials removed

[12]Title 10, Section 20.2002, "Method for Obtaining Approval of Proposed Disposal Procedures," of the *Code of Federal Regulations* supercedes these requirements.

[13]The U.S. Department of Transportation (DOT) promulgated its regulations for the transportation of radioactives wastes in 1979 (44 FR 1851).

Table 4 **Past and Current Commercial LLW Disposal Facilities in the United States.** Taken from EG & G Idaho, Inc. (1994), unless otherwise noted.

Site	Operational Period	Original Licensing Authority (year)	Status	Area (acres)[a]	Disposal Volume (10^6 ft^3)	Waste Form Characteristics			Comments
						By-product material (10^6 Ci)	Source Material (10^6 lbs)	Special Nuclear Material (lbs)	
Beatty, Nevada	1962–1992	AEC (1962)	Closed	80 (60)	4.7	0.64	4.0	605	A site adjacent to the now-closed LLW disposal facility is currently operated as a RCRA- and PCB-approved disposal facility. [b]
Maxey Flats, Kentucky	1963–1977	State (1962)	Closed	280	4.7	2.4	0.533	950	Designated as an EPA Superfund site in 1986. Remediation completed in 1991.
West Valley, New York	1963–1975	State (1963)	Closed	3345 (22) [c]	2.5	1.3	1	125	LLW operations ceased in 1975 when burial caps leaked contaminated water.
Richland, Washington	1965–present	AEC (1965)	Open	100 [d]	13.6 [e]	36.1 [e]	13.5 [f]	351 [f]	Collocated within the Hanford nuclear reservation. Disposal site leased from the Government. Disposal fees lower than Barnwell, but higher than Envirocare.
Barnwell, South Carolina	1969–present	State (1971)	Open	300	24.8 [e]	12.8 [e]	33.6 [f]	6739 [f]	Originally licensed for above-ground LLW storage. In 1971, LLW burial was approved. Highest disposal fees in the country.
Sheffield, Illinois	1968–1978	AEC (1967)	Closed	170 (20)	+3	3	0.06	126	Attempts to expand disposal capacity in 1975 were unsuccessful because contaminated leachate was detected, effectively ending site operations. In 1988, the Sheffield operator agreed to a 10-year monitoring plan with the state.
Clive, Utah	1991–present	State (1991)	Open	540	25.0 [g]	11.3 [g]	NA	NA	Initially approved as a DOE uranium mill tailings disposal site. Subsequent license amendments were received for the disposal of naturally occurring radioactive material (NORM – 1987), LAW (1991), mixed LLW (1993), AEA Section 11e.(2) materials [h] (1994), and Part 61 Class A LLW (2000).

a. Actual disposal area, in parentheses, smaller than area comprising disposal site. Reported disposal volumes can be converted to units of cubic meters by multiplying values by 0.028317.
b. In June 1988, the site operator, U.S. Ecology received a joint State-Federal RCRA permit to dispose of hazardous chemical wastes at a location adjacent to the LLW disposal site (Howekamp, 1996, p. 3). Pre-RCRA classified waste types had been disposed at this site since 1970. In 1978, the company also received EPA approval to operate a PCB storage and disposal facility at the Beatty site.
c. Site owned by New York State includes multiple radioactive waste management areas.
d. Hanford nuclear reservation encompasses an area of 1000 acres.
e. Data for the period 1995–98 taken from Fuchs (1996, p. 6; 1997, p. 6; 1998, p. 6; 1999, p. 7). Data for the period 1999 though June 2005 taken from MIMS.
f. Data only through 1994.
g. Data for period June 1992 through May 2005 taken from MIMS.

during trench excavation, compacted, and graded to create an earthen mound cap necessary to prevent rain water ponding and to promote runoff. The earthen cap was then seeded to grow a short-rooted protective grass cover. To preclude inadvertent human intrusion, a security fence surrounded the disposal sites. The near-surface disposal method assumed that the nature and rates of natural processes acting on the earthen trench system would be sufficient to slow the movement of radionuclides from the disposal trenches to the accessible environment until they had decayed to acceptable background levels found in nature (EG&G Idaho, Inc., 1994, p. 4).

In 1973, the AEC asked the NAS to independently review the shallow-land disposal practices at its facilities. The AEC was particularly interested in identifying " undesirable existing conditions and disposal practices..." as well as identifying corrective actions, such as "changes in current burial practices, changes in conditioning of [LLW] materials for burial, and special treatment of the ground prior to disposal...." See Pittman (1973). The AEC requested the review because routine monitoring at some of the AEC sites had begun to reveal that the disposal trenches were not containing the wastes and that radionuclides were being released (NRC, 1977b, p. 17). At the time, the AEC was particularly concerned about the long-term management of the TRU constituents of its wastes (National Research Council, 1976). In 1976, the NAS published its findings and recommendations following the review of solid LLW management practices at AEC facilities. Although the NAS found no serious deficiencies in past Federal disposal practices, it did make numerous administrative, as well as technical recommendations for the AEC to consider.[14]

2.3 Early Performance Issues

After several years of operation, the West Valley, Maxey Flats, and Sheffield[15] sites began to encounter surface and/or ground-water management problems (Fisher, 1986). These problems, coupled with other early LLW disposal practices, resulted in the unexpected release and transport of radionuclides from the disposal sites. Key failure modes included waste container exhumation due to surface erosion, ground failures (subsidence) caused by inadequate waste container compaction, and the migration of contaminated leachate from unlined disposal trenches. Because the disposal units were in effect "leaking," decisions were made to suspend operations and close the sites in the 1970s. Carter et al. (1979) describes forensic case studies of past performance for several of the early disposal sites.

The remaining LLW sites had problems of a different type. The Governors of Nevada and Washington temporarily closed the Beatty and Richland sites, respectively, in 1979 as a result of waste packaging violations and transportation safety issues. When the volume of waste shipped to the South Carolina site began to increase because of closures and interruptions at the other sites, coupled with a large increase in the generation of LLW following the Three Mile Island incident (NRC Special Inquiry Group, 1980), the State was concerned that the facility would bear sole responsibility for the disposal of the Nation's commercial LLW. As a result, in 1979, the Governor of South Carolina ordered that waste acceptance operations be scaled back by 50 percent over a 2-year period (EG&G Idaho, Inc., 1994).

[14]Later, as part of the 10 CFR Part 61 rulemaking process, the NRC conducted its own independent review of early LLW disposal site performance. Clancy et al. (1981) documented this independent review.

[15]Actually, contaminant transport was not discovered at the Sheffield site until after operators of the closed site attempted to reopen with expanded disposal capacity (EG&G Idaho, Inc., 1994, pp. 37–38).

To address some of the past performance concerns and to develop geohydrologic guidelines[16] that could be used to establish technical criteria for selecting, evaluating, licensing, and operating new LLW disposal sites, the U.S. Geological Survey (USGS) received direct LLW appropriations for the first time in 1975 leading to the preparation of various reports (Schneider et al., 1982, p. 57). These reports include Schneider et al. (1982), Dinwiddie and Trask (1987), Trask and Stevens (1991), Stevens and Nicholson (1996); and Morganwalp and Buxton (1999). To reduce the potential for the environmental transport of radionuclides at disposal sites, the NAS independently recommended that arid sites in the West be considered based on the view that the geohydrologic settings there would be less complex and hence performance could be more reliably predicted (National Research Council, 1976, pp. 67–68). Incidentally, the USGS reached this same opinion as early as 1974 when it recommended 17 types of earth-science information needed to predict the rate and direction of radionuclide transport. See Papadopulos and Winograd (1974). Other recommendations were made that some form of engineered barrier, working in concert with the natural system (geosphere), be integrated into future LLW facility designs (Battelle Memorial Institute, 1976, pp. 24, 48).

Technical issues notwithstanding, LLW generators were still faced with the practical matter of a reduction in existing disposal access because of site closures and operational interruptions. In addition, the geographic location of the remaining disposal facilities (mostly in the West) was mismatched with the geographic location of most of the waste generation (in the East). The three remaining states with operating sites made it clear that they would not continue to accept all of the Nation's LLW (GAO, 1983, p. 7).

[16]Later published as Bedinger (1989).

3 CONGRESSIONAL ACTIONS

Congress abolished the AEC in 1974. The newly created NRC subsumed the AEC regulatory functions and the Energy Research and Development Administration (ERDA - which was later absorbed into DOE) took over the atomic energy promotional functions.

3.1 Background

In a review prepared for OTA, Metlay (1981a, p. 203) notes that during the formative years of domestic radioactive waste management policy (1941-75), the waste management issue did not receive very high priority. National policy focused on promoting the civilian use of nuclear energy (e.g., "Atoms for Peace"). The Government assumed that SNF would be reprocessed and its residual uranium and plutonium would be recycled as fuel (Op cit., p. 205). When the management of radioactive waste finally did receive attention, it focused on the management of the more toxic, longer lived radionuclides (Metlay, 1981b, pp. 233-239).

In response to the National Environmental Policy Act of 1970 (NEPA) (Public Law 91-190),[17] as well as critical reviews by GAO (1968, 1971, 1974), the AEC undertook several initiatives intended to place greater Federal emphasis on the management of radioactive wastes. In June 1969, the AEC proposed for the first time the development of repositories for the geologic disposal of solidified HLW on Federal land (AEC, 1970).[18] Next, the AEC issued a plan describing how it intended to manage radioactive legacy waste from the defense program (AEC, 1972). In 1974, the AEC issued a rule on the environmental effects of the uranium fuel cycle as a result of the increased licensing and operation of commercial nuclear power plants (AEC, 1974a). This rule was later supported by a draft EIS (DEIS - AEC, 1974c).[19] The AEC also proposed to prohibit the burial of TRU-contaminated commercial radioactive waste whose concentration exceeded 10 nCi/g (AEC, 1974b). Waste material exceeding this concentration limit would have been consigned to a Federal retrieval storage facility pending the development of a disposal facility for TRU waste (Op cit.). In 1976, the newly created NRC issued a final EIS (FEIS) to aid in the assessment of the proposed wide-scale use of mixed-oxide (MOX) fuel in light water nuclear power reactors. The environmental impacts of potential radioactive waste management activities due to the recycling of MOX plutonium were discussed in Volume 3 (Section H). In that FEIS, it was noted that LLW volumes were not significantly affected by the recycle option (NRC, 1976,

[17]NEPA initially requires Federal agencies to integrate environmental values into their decisionmaking processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. NEPA also requires that all Federal agencies prepare an environmental impact statement (EIS) "for major actions significantly affecting the quality of the human environment...." To meet this basic requirement, Federal and State Governments, at all levels, now routinely prepare detailed EIS. See Leopold et al. (1971).

The Council on Environmental Quality (CEQ) develops regulations that implement NEPA. CEQ defines the "scoping" of an EIS at 40 CFR 1501.7 as "an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to the proposed action...."

[18]Designated Appendix F, "Siting of Fuel Reprocessing Plants and Related Waste Management Facilities" (34 FR 8712). The policy was later finalized in 1970 (35 FR 17530).

[19]Following the reorganization of the AEC, ERDA issued a revised generic DEIS which, in part, addressed the earlier public comments received on the version first issued by the AEC. Later, DOE (1979) updated the DEIS for a second time, acknowledging (pp. 2.1-2.2) LLW as part of the nuclear fuel cycle, but not addressing the environmental impacts of this waste form as it was the subject of an ongoing NRC rulemaking (i.e., 10 CFR Part 61). DOE published the final generic EIS in October 1980.

"Executive Summary," p. ES-10).

Congress abolished the AEC when it passed the Energy Reorganization Act of 1974 (Public Law 93-438). The act placed the AEC regulatory functions into the NRC and placed the atomic energy promotional functions within ERDA, which was later absorbed into DOE following the Department's creation in 1977. The NRC was given the authority to regulate certain Federal HLW storage and disposal activities. However, a number of other Federal radioactive waste activities were exempted from this independent regulatory authority. In its 1976 report, the NAS recommended greater Federal leadership in the management of radioactive wastes (National Research Council, p. 77). In a later review, GAO (1977) noted several continuing problems, including gaps in the NRC's regulatory authorities; the lack of demonstrated technologies for managing certain defense, commercial, and TRU wastes; and technical concerns within the scientific community regarding the feasibility of long-term geologic disposal. Based on recommendations for improved coordination of waste management policies and programs (U.S. Radiation Policy Council, 1980a), the Federal Government subsequently intensified its efforts to coordinate its radioactive through the U.S. Office of Management and Budget (OMB). See EPA (1988, pp. 1-3-1-4).

At the direction of Congress (through Public Law 95-601), the NRC received appropriations in 1978 to undertake a study to assess the possible expansion of the Commission's licensing and regulatory authority to include categories of existing and future Federal radioactive waste storage and disposal activities not presently subject to such authority. In its subsequent report (NRC, 1979b), the Commission recommended that its regulatory authorities be expanded over certain DOE waste management activities. Specifically, the Commission recommended (Op cit., p. 3) the following:

- The NRC licensing authorities should be extended to cover all new DOE facilities for the disposal of TRU waste and nondefense (commercial) LLW - designated as *Option A*.[20]

- A pilot program should be established to test the feasibility of extending NRC regulatory authority on a consultive basis to DOE waste management activities not currently covered by the NRC's existing authorities - designated as *Option B*.

Congress never adopted the NRC's 1979 recommendations. Instead, they authorized DOE to build a geologic repository for the disposal of defense-generated TRU wastes near Carlsbad, New Mexico. This facility, referred to as the Waste Isolation Pilot Plant (WIPP), has been in operation since May 1998 and is exempt from NRC regulation. (See Appendix B of this report for a brief discussion of the WIPP program.)

As noted in the next section of this report, the NRC was already developing a LLW regulatory framework when Congress passed the LLWPA, which established Federal policy concerning the management of commercial LLW. DOE was to continue to manage Government-owned LLW. (Also see Appendix A of this report.)

Lastly, from time to time, the issue of whether the NRC should seek authority to regulate "low activity materials" (and wastes) has been raised. This debate applies to naturally occurring radioactive materials (NORM) as well as to naturally occurring or accelerator-produced materials (NARM). Austin (1988, p. 24), for example, notes that the Commission sought authority to manage such materials in the past,

[20] Before the NRC issued its recommendations, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 96-604) that further extended the NRC's licensing authority to include uranium mill tailings and mill tailings sites. See also Landa (1980).

which Congress previously declined to provide. However, in recent years, the debate has reemerged (National Council on Radiation Protection and Measurements - NCRP, 2005) and Congress recently directed the Commission to take action for the first time to regulate some of these materials. Refer to Section 3.5 of this report for a discussion of the management of LAW.

3.2 The NRC and 10 CFR Part 61

The NRC began operations on January 19, 1975. The NRC (like the AEC before it) focused its attention on several broad issues essential to protecting public health and safety. Initially, the NRC (and the AEC) regulated LLW using a collection of generic regulations specified in 10 CFR Part 20, "Standards for Protection Against Radiation," 10 CFR Part 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material," 10 CFR Part 40, "Domestic Licensing of Source Material," and 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material." However, in response to the needs and requests expressed by the public, the states, Congress, industry, and others, one of the earliest rulemaking efforts the Commission was a set of comprehensive requirements for licensing the land disposal of commercial LLW.

In 1976, the GAO published a report that reviewed existing private and Federal LLW disposal practices in light of the reported operational and performance irregularities identified at some disposal sites. Among other things, that review identified the need for studies and criteria to judge the suitability of potential LLW disposal sites, as well as the need for standards to determine when releases from disposal sites reached unacceptable levels and required corrective action (GAO, 1976, pp. 19–21). In parallel to the GAO review, the NRC had formed a task force to examine Federal and Agreement State programs that regulated commercial LLW disposal (NRC, 1977a). Among other things, the task force (NRC, 1977b, p. ii) recommended that the NRC "accelerate" the development of its LLW regulatory program. Shortly thereafter, the NRC (1977d) published a program plan that described the elements and schedules for implementing an integrated LLW program. This program plan included the development of an EIS and a yet-to-be-defined LLW regulation.

The NRC began to develop its LLW regulation in 1978 by relying on an extensive NEPA scoping process.[21] Early in that process, the Commission determined that comprehensive standards, technical criteria, and licensing procedures were needed to ensure public safety and long-term environmental protection in the licensing of new sites, as well as the operation and closure of existing ones. The staff determined that the most viable regulatory approach would be to develop a regulation generally applicable to land disposal of most types of commercial LLW. One challenge was that the regulation had to apply to a broad range of geologic/geomorphic conditions within the United States as well as to disparate waste streams. Another challenge was that early in the scoping process, the NRC staff determined that inadvertent human reentry into a LLW disposal area could not be precluded (NRC, 1980, 45 FR 13105). Consequently, the staff explored ways of classifying LLW for use in standardized exposure scenarios as a way of predicting potential doses to receptors. See Rogers (1979) and Rogers et al. (1979). The staff also considered both generic and specific

[21] In deciding to develop a LLW regulation, the NRC determined that the promulgation of 10 CFR Part 61 qualified as a major Federal action, as defined by NEPA.

CEQ is responsible for developing regulations that implement NEPA. CEQ defines the scoping of an EIS at 40 CFR 1501.7 as "an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to the proposed action...."

disposal methods in the context of an EIS that examined the costs, benefits, and impacts of a base-case and alternative disposal concepts. From those analyses and studies, the staff proposed performance objectives and technical criteria in a draft regulation designated as 10 CFR Part 61 (NRC, 1981b).

Following several years of development, the Commission issued a final 10 CFR Part 61 rule in December 1982 (NRC, 1982b). The "umbrella" regulation covered all phases of shallow, near-surface LLW disposal from site selection through facility design, licensing, operations, closure, and postclosure stabilization to the period when active institutional controls end. The regulation requires the use of engineered features in concert with the natural characteristics of the disposal site to contain and isolate the wastes. The regulation also established the procedures, criteria, and terms and conditions on which the Commission would issue and renew licenses for the SLB of commercially generated LLW. (See Section 6 of this report.) Among other things, 10 CFR 61.55, "Waste Classification," introduced a three-tier waste classification system for LLW based on the concentrations of the longer lived radionuclides. These classes are designated Class A, Class B, and Class C in ascending order of potential radiological hazard, and the regulation includes specific design standards applicable to each waste class.

3.3 The Low-Level Radioactive Waste Policy Act of 1980

At the same time the NRC established a LLW regulatory framework, Congress passed the LLWPA. This act set forth a Federal policy that LLW disposal was best handled on a regional basis. The act made states responsible for disposing of commercial LLW generated within their borders[22] and encouraged the states to form interstate compacts to establish regional disposal sites, rather than establishing 50 separate disposal sites. The act was passed in response to policy recommendations that addressed past and present LLW management issues from several states[23] and state-supported organizations, including the National Governors' Association and the National Conference of State Legislatures. The other key provision of LLWPA allowed compacts to exclude commercial LLW generated outside their borders.

Following passage of the act, the states began to enter into negotiations to form the required compacts. The states were generally committed to the compact arrangement. Shortly after the act's passage, 40 states had entered into agreements or were negotiating to form seven required compacts (GAO, 1983, p. 16). However, in its review of the compact-forming agreement process, GAO observed that the administrative agreement process (Table 5) was "slow and drawn-out." They also observed that only three of the tentative compact regions had operating disposal sites, and those sites had been in existence before the passage of the act. GAO (1983, pp. 20–21) estimated that once a compact agreement had been entered into, it would take an additional 5 years before the disposal site was ready to receive LLW. Nevertheless, despite the progress being made, GAO (1983, p. 15) concluded that no new disposal sites would be operating until sometime after 1988, 2 years after the Congressionally-mandated date of January 1, 1986.

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[22]By January 1, 1986, except for LLW generated by the Federal Government.

[23]Washington State, in conjunction with Nevada and South Carolina, sought passage of the LLWPA because of the imbalance between the volumes of LLW those states were generating and the wastes they were receiving for disposal from outside their borders. See Washington State Department of Health (2004, p. 43).

Table 5 **Administrative Process for Establishing LLW Compacts.** Taken from GAO (1983, p. 10). Compacts formed through this process are described later in Table 6 of this report.

Step	Description of Activity
1	States negotiate among themselves to form regional Interstate Compacts of two or more states.[a]
2	Once formed, proposed Interstate Compacts draft Interstate Compact Agreements.
3	Drafted Interstate Compact Agreements are approved by the state legislatures and signed by the Governors in each state participating in the Interstate Compact.
4	Ratified (approved) Interstate Compact Agreements are to be approved by a majority of both Houses of Congress.
5	Following Congressional approval, each Interstate Compact is to form a commission to administer the compact agreement.[b, c]

a. Alternatively, if a state chooses not to participate in the Interstate Compact process, it must indicate its intent not to do so. States deciding to act alone to meet their own LLW disposal needs still need to undertake the process steps outlined in Item b, below.
b. Once formed, the Interstate Compact Commission is responsible for ensuring that its member states (i) screen the region defined by the Interstate Compact to identify candidate disposal sites, (ii) select a preferred site and perform the required environmental assessment, (iii) prepare a LLW license application, and (iv) construct and operate the disposal facility, once the license application is approved.
c. Compacts can choose to refer the site selection/license application development process to a private entity.

One of the problems with the existing law was that it did not specify penalties, such as denial of access to existing disposal facilities, if Congressional deadlines for developing new disposal facilities were not met. When it became apparent that the deadline for operating new disposal sites would not be met, decisionmakers recognized that adjustments to the 1980 act were needed. Moreover, the three states with operating disposal sites made it clear that they would not continue to accept all of the Nation's commercial LLW. But before Congress could amend the 1980 act, an "understanding" was necessary between Nevada, South Carolina, and Washington — the states with operating disposal facilities — and the 47unsited states. Following negotiations, these three states agreed to continue to receive out-of-state wastes for an additional 7 years, subject to certain conditions later reflected in the 1985 amendments to the act (NRC, 1989c, p. 13).

3.4 The Low-Level Radioactive Waste Policy Amendments Act of 1985

On January 15, 1986, Congress passed the Low-level Radioactive Waste Policy Amendments Act of 1985 (LLWPAA) (Public Law 99-240). The LLWPAA extended the original January 1, 1986, deadline to develop new disposal facilities by 7 years to January 1, 1993. Because new disposal facilities were expected to be operational by the 1993 date, the existing states with operating LLW disposal facilities had the right, at that time, to decline commercial LLW from outside of their respective compacts. In exchange, the unsited states and regions were required to meet newly established milestones and deadlines. See Table 6.[24] If states failed to comply with the specific LLWPAA milestones, the three states operating disposal facilities were authorized to deny disposal access to those states in violation of the milestones. The LLWPAA also included the following provisions:

- establishing financial penalties on waste disposed of at existing disposal facilities if certain milestones were not met

[24] In a 1992 decision [*New York vs. United States et al.* (505 U.S. 144)], the U.S. Supreme Court struck down the "take title" provision requiring that states must take title to their LLW if a disposal facility were not available by 1996.

Table 6 Milestones, Deadlines, and Penalties Defined in the LLWPAA

Milestone Date	LLWPA Requirement	Penalty(ies)
By July 1, 1986	Each state shall join a regional compact by ratifying compact legislation or, by the enactment of legislation or the certification of the Governor, indicate its intent to develop its own LLW disposal facility.	2× the surcharge ($20/ft^3$) for the period July 1, 1986, through December 31, 1986. Access to existing disposal sites may be denied after January 1, 1987.
By January 1, 1988	Each compact region or the host state in which its LLW disposal facility is to be located shall develop a siting plan for such a facility providing detailed procedures and a schedule for establishing a facility location and preparing a facility license application and shall identify a developer to implement such plan. Each nonsited compact region shall identify the state in which its LLW disposal facility is to be located, or shall have selected the developer for such facility and the site to be developed, and shall identify a developer to implement such plan.	2× the surcharge ($40/ft^3$) for the period January 1, 1988, through June 30, 1988. 4× the surcharge ($80/ft^3$) for the period July 1, 1988, through December 31, 1988. Access to existing disposal sites may be denied after January 1, 1989.
By January 1, 1990	Each state (or the designated disposal facility developer) shall have submitted a complete application (as determined by the NRC or the appropriate agency of an Agreement State) for a license to operate an LLW disposal facility or, in lieu of the license application, the Governor's written certification to the NRC that such state will be capable of providing for, and will provide for, the storage, disposal, or management of any LLW generated within such state and requiring disposal after December 31, 1992, and include a description of the actions that will be taken to ensure that such capacity exists.	Access to existing disposal sites may be denied after January 1, 1990.
By January 1, 1992	A complete application (as determined by the NRC or the appropriate agency of an Agreement State) shall be filed for a license to operate an LLW disposal facility within each nonsited compact region or within each nonmember state.	3× the surcharge ($120/ft^3$ maximum) for the period January 1, 1992, until complete application is filed or until December 31, 1992.
By January 1, 1993	Each state (or its compact region, where applicable) is expected to have provided a disposal facility for all the LLW it generates, and disposal rights at the three existing disposal facilities (Barnwell, Beatty, and Richland) will end. If a state (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, those states in the compact region shall, upon the request of the LLW generator or owner, be obligated to take title to and possession of the waste, or assume financial liability for costs associated with its storage and maintenance. If a state (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, the state (or states) will have to forfeit rights to rebates of previous surcharge payments made by LLW generators (or owners) because of the state's failure to meet earlier LLWPAA milestones.	1/36 of the rebates collected for the period from January 1, 1990, through December 31, 1992, returned to generators monthly, with interest. Rebates to generators to continue until January 1, 1996, or until state provides for disposal.
By January 1, 1996	If a state (or, where applicable, a compact region) is unable to provide a disposal facility for its LLW, those states in the compact region shall, upon the request of the LLW generator or owner, be obligated to take title to and possession of the waste.	*In 1996, the US Supreme Court found that this provision of the LLWPAA was unconstitutional.*

- assigning responsibility to the Federal Government for disposing of commercial LLW exceeding 10 CFR Part 61 Class C concentration limits

- specifying which categories of LLW were exempt from commercial disposal facilities

The act also gave Federal agencies expanded responsibilities in the area of commercial LLW (see Table 7) and assigned specific new responsibilities to DOE and the NRC. Under the LLWPAA, DOE is required to do the following:

- dispose of GTCC-designated wastes

- manage the collection of and disbursal of LLWPAA-levied surcharges[25]

- provide financial and technical assistance to the states and compacts

- prepare certain status reports on the management of national LLW inventories

For its part, the NRC was required to do the following:

- review all LLW disposal facility license applications

- develop standards and procedures for exempting certain LLW from disposal in licensed facilities

- provide regulatory and technical assistance to Agreement States

- determine procedures for granting emergency access to LLW facilities for wastes generated in other regions[26]

3.5 *De Minimis* Regulatory Levels and the Below Regulatory Concern Policy

Section 10 of the LLWPAA also requires that the NRC establish standards for determining when radionuclides are present in waste streams in sufficiently low concentrations or quantities as to be "below regulatory concern" (BRC), thereby potentially exempting them from NRC LLW regulation. Before the passage of the LLWPA in 1980, the staff had already indicated its intent to formally establish a *de minimis* level[27] for commonly used, short-lived radioisotopes when it announced the availability of a preliminary draft version of the 10 CFR Part 61 regulation (NRC, 1980). The staff provided additional clarification of its *de minimis* position in the draft 10 CFR Part 61 DEIS. As discussed in that position, radionuclides with very short half-lives could, on a case-by-case basis, be exempt from disposal under 10 CFR Part 61. Alternatively, if authorized, the exemption would generally require storage of the waste for a duration of 10 half-lives of decay (for the dominant radionuclide). Afterwards, the licensee could dispose of the wastes in a manner consistent with its nonradiological properties (NRC, 1981c, Volume 2, p. 2-8). Following public review of the DEIS, over one-fourth of the commenters endorsed the *de minimis* concept (NRC, 1982b, 47 FR 57452). However, the fundamental concern was not whether a generic or a case-by-case approach should be taken, but rather the

[25]"Surcharges" were financial penalties imposed by DOE on waste generators if certain LLWPAA milestones were not met. These penalties were in addition to the basic disposal charges imposed by the disposal facility operator. See Table 6.

[26]Promulgated as 10 CFR Part 62, "Criteria and Procedures for Emergency Access to Non-Federal and Regional Low-Level Waste Disposal Facilities" (NRC, 1989a).

[27]The staff defined a *de minimis* level as one in which the radioactivity in the waste is sufficiently low that it can be disposed as ordinary, nonradioactive trash (45 FR 13106).

Table 7 **Federal Responsibilities for the Management and Disposal of Commercial LLW** (as defined by various Federal statutes)

Agency	Responsibility
U.S. Department of Energy	Overall lead agency for national planning of commercial LLW management and disposal. Assist in the formation of Interstate Compacts and establishing site selection procedures. Also undertake (or sponsor) research and development (R&D) in the area of LLW disposal technology, and transfer that technology to the private sector.
U.S. Department of Transportation	Regulate waste containers, transportation vehicles, and other interstate aspects of LLW transport. [a]
U.S. Environmental Protection Agency	Establish overall Federal radiation protection guidance and environmental standards. [b]
U.S. Geological Survey	No basic responsibility for the management of LLW. Conduct basic research in the geological sciences and develop basic data for application in the development of disposal criteria. Also provide technical advice in the assessment of specific disposal sites.
U.S. Nuclear Regulatory Commission	Regulate and license the commercial and nondefense governmental use of source, by-product, and special nuclear material, including the licensing of commercial LLW disposal facilities.

a. Through a memorandum of understanding, the NRC and DOT have delineated their respective responsibilities for the transportation of radioactive wastes. The NRC regulates packaging for wastes containing high amounts of radioactive materials to assure safety and safeguards during transportation. DOT regulates all other aspects of radioactive waste transportation.
b. See Section 7.4.1 of this report for more information.

need for Commission action to develop *de minimis* standards as soon as possible (47 FR 57453).

In its draft rule, the Commission expressed its preferred position to review *de minimis* waste streams on a case-by-case basis, consistent with the recommendations of the U.S. Radiation Policy Council (1980b). In doing so, the Commission provided guidance in the *Federal Register* notice on what should be included in any exemption petition. See 47 FR 57453. [28] The Commission also noted that it intended to work over the next several years to define generic limits for *de minimis* waste streams (Op cit.). In support this statement, the staff subsequently published an impacts analysis methodology (Oztunali and Roles, 1984) that prospective petitioners could use to determine radiological doses for *de minimis* waste streams. The calculational approach employed in that methodology (Oztunali et al., 1981) was similar to that used in the development of the 10 CFR Part 61 DEIS. Later, a compendium computer code (Forstom and Goode, 1986) that implemented the methodology was issued for public comment.

In August 1986, the Commission issued a policy statement outlining its plans to establish certain new rules and procedures to exempt specific radioactive waste streams from regulation due to

[28] In a different regulatory context, the Commission had already established the precedent for granting regulatory exemptions to disposal of certain radioactive waste streams (NRC, 1981a). At 10 CFR 20.306, for example, the Commission set regulatory exemption levels for specified concentrations of tritium and carbon-14 without regard to their radioactivity (46 FR 16231). The Commission was already aware of the academic view that certain radioactive waste streams could be considered of no regulatory concern from a public health and safety standpoint and, as such, they could be exempt from regulation on a case-by-case basis depending on the recommendations of the Radiation Policy Council.

the presence of radionuclides in sufficiently low concentrations or quantities as to be BRC. The subsequent BRC Policy Statement (NRC, 1986b) contained criteria that, if adequately addressed, would allow the Commission to act expeditiously in providing the needed regulatory relief. The NRC published these criteria as Appendix B [29], "Procedure for Imposing Requirements by Order, or for Modification, Suspension, or Revocation of a License, or for Imposing Civil Penalties," to 10 CFR Part 2, "Rules of Practice for Domestic Licensing Procedures and Issuance of Orders." To establish a consistent regulatory framework for decisionmaking, the Commission later issued a second BRC Policy Statement in July 1990 (NRC, 1990). In that policy statement, the Commission proposed that if radioactive materials did not expose individuals to a dose of more than 1 millirem per year (mrem/yr), or a population group to more than 1000 person-rem per year (collective dose), the waste stream in question could be eligible for an exemption from full-scale regulatory control (55 FR 27526–27527). However, this exemption would not be granted automatically; the NRC would consider requests from licensees that met the dose criteria through its rulemaking (licensing) process under 10 CFR Part 2.

The Commission intended that its BRC policy would apply to consumer products containing small amounts of nuclear materials and other sources of very-low levels of radiation, such that those types of wastes could safely be disposed in sanitary landfills. The policy also provided a framework for making future exemption decisions and reviewing previous exemptions by which small quantities of LLW materials could be largely exempted from existing regulatory controls (NRC, 1986c, p. 1). Johnson (1988) noted that unlike the *de minimis* position, which allowed the disposal of trivial amounts of LLW, the Commission's BRC policy implied the use a cost-benefit analysis, taking into account current technology, when deciding on regulatory control exemptions.

Both Congress and the public received the NRC's proposed BRC policy unfavorably. See Walker (2000, p. 120) and National Research Council (2002, pp. 52–53). Later, Congress enacted the Energy Policy Act of 1992 (H.R. 776) to revoke the Commission's earlier policy statements. As a result, the Commission officially withdrew the policy in June 1993 (NRC, 1993b).[30]

Both the Advisory Committee on Reactor Safety (ACRS) and the Advisory Committee on Nuclear Waste (ACNW) commented on the staff's *de*

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[29]Entitled "General Statement of Policy and Procedures Concerning Petitions Pursuant to §2.802 for Disposal of Radioactive Waste Streams Below Regulatory Concern."

[30]It is also worth noting that the Federal Radiation Council (FRC or the Council) had previously focused on the matter of how to regulate very-low levels of radiation. The FRC was established by Congress in 1959 (Public Law 86-373) to provide recommendations to the President on Federal policy on radiation matters affecting health. Their charter also included developing guidance for all Federal agencies in the formulation of radiation standards and in the establishment of cooperative programs with the states.

Between 1960 and 1970, the FRC issued nine reports on a number of radiation protection issues. In all of those reports, the FRC expressed the philosophy that "guidance for radiation protection involves achieving a balance between the risk of radiation-induced injury and the benefits derived from the practice causing the exposure to radiation. An implicit part of such a balance is a necessity for considering the relation between the difficulties involved in reducing the radiation exposure by a given amount and the risk that might be associated with that amount of exposure...." However, in at least three of their reports – *Report No. 5* (FRC, 1964, p. 13), *Report No. 7* (FRC, 1965, p. 6), and *Report No. 8* (FRC, 1967, p. 43) – the Council essentially acknowledged that there is some (yet-to-be-defined) radiation exposure level at or below which individuals may be exposed without experiencing a significant increase in some risk of injury.

The FRC was abolished in December 1970 and its functions were transferred to the EPA Administrator.

minimis position and the BRC Policy Statements. Nearly one-fourth of their past letters (10 letters) were dedicated, wholly or in part, to these issues. See summary in Section 10.3.2 of this report.

4 EFFORTS TO SITE NEW LLW DISPOSAL FACILITIES

The objectives of the LLWPA and LLWPAA are to provide for more LLW disposal capacity on a regional basis and distribute the responsibility for the management of LLW equitably among the states. By 1998, in response to these two acts, 44 states entered into 10 interstate compact agreements. Compact membership varied from two to eight states per compact. As part of the compact agreement process, host states for the future disposal facilities were agreed-to and site-screening commenced. For those that had not done so, designated host states entered into Agreement State programs with the NRC and subsequently developed the regulatory and technical capabilities necessary to administer their respective programs.[31] By definition, this included developing a regulatory framework compatible with the requirements of 10 CFR Part 61 and other NRC guidance (Section 6 of this report). In most cases, host states assigned the responsibility for implementing their respective programs to existing state agencies or created new or quasi-state authorities. Two regional compacts (Nebraska and California) delegated the disposal facility development responsibilities to private sector firms, but retained the regulatory functions.

As a result of these efforts, 7 out of 10 of the regional compacts met the first three milestones of the LLWPAA leading to the submission of license applications. Regulatory authorities in four states (California, Illinois, Nebraska, and Texas) received license applications requesting authorization to construct new disposal facilities. However, the host state for the Southwestern Interstate LLW Compact, California, was the only state able to proceed sufficiently in the licensing process to authorize the issuance of a construction authorization. See Table 8. Citing industry sources, GAO (2004, p. 9) reported that national expenditures on various disposal facility development efforts since the passage of the LLWPAA may have reached approximately $1 billion.

Despite these overall efforts, none of the states or compacts have successfully developed new LLW disposal facilities under the LLWPAA framework. In its 1989 review, OTA found that some states enacted bans to legally restrict SLB disposal even though Federal regulations found this disposal method technically sound. OTA cited other issues, including the rising costs of LLW disposal (at the time of the study, it had tripled in 20 years) and the management of mixed wastes. For example, the State of California granted a contingent construction authorization for a new facility at Ward Valley in 1993, but the necessary land transfer from the Federal to the state Government was never completed, effectively ending the facility's startup. Administrative Law Judges in Texas denied a license application to construct a LLW disposal facility at the proposed Sierra Blanca site (Hudspeth County) in 1998 citing both geologic and socio-political factors (State of Texas, 1998). As a consequence, commercial LLW generators continue to rely on the existing disposal sites. Only one new disposal facility has actually been licensed - the Envirocare LLW disposal facility in Clive, Utah - and this was accomplished outside of the LLWPAA framework.[32]

[31]Title 10, Part 150, "Exemptions and Continued Regulatory Authority in Agreement States and in Offshore Waters Under Section 274," of the *Code of Federal Regulations* contains the current Commission regulations regarding the NRC's relationship with the Agreement States.

[32]S.K. Hart Engineering (later to become Envirocare of Utah) was licensed by the Utah Department of Environmental Quality in 1987 to accept NORM waste, in the form of uranium mill tailings, for disposal. In 1991, the state amended the Envirocare license to permit the disposal of Class A LLW, including mixed wastes, from all states except those in the Northwest Interstate Compact. See Table 4.

Table 8 **LLW Compacts and LLWPA Milestone Status.** Host state for the disposal facility is designated in bold type. "C" means completed disposal facility development milestones. Compiled using GAO (1992, 1999, and 2004) and other cited sources.

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
APPALACHIAN	Delaware Maryland **Pennsylvania** West Virginia	1985C	*see Comments*	—	—	—	Voluntary siting process suspended in 1991 because no municipality volunteered to host the disposal site.
CENTRAL	Arkansas Kansas Louisiana **Nebraska** Oklahoma	1982C	1989C	1990C	*see Comments*	—	A 1998 Nebraska denial of an application to construct was overturned in April 1999 by a U.S. district court. In May 1999, Nebraska legislature voted to withdraw from Central Interstate Compact. In 2004, a Federal appellate court ruling affirmed an earlier Federal district court decision that Nebraska, as a designated host state, is liable for $151 million in damages for reneging on its obligations to the Central Interstate Compact to build a disposal facility by denying a license application for reasons not related to the merits of the initial application. See Central Interstate Low-Level Radioactive Waste Commission (2004, pp. 8–9).
CENTRAL MIDWEST	**Illinois** Kentucky	1984C	1991C	1991C *see Comments*	—	—	In October 1992, the Illinois legislature rejected the conclusions of an earlier siting decision, effectively ending the license application review process for the Martinsville site (New Jersey Low-Level Radioactive Waste Disposal Facility Siting Board, 1999, p. 27). Since then, a new siting review process has been established, as well as a cost-benefit analysis to determine whether a disposal facility should be built based on current LLW volumes.
MIDWEST	Indiana Iowa **Michigan** [a] Minnesota Missouri **Ohio** Wisconsin	1982C	*see Comments*	—	—	—	In 1997, the Midwest Interstate Compact Commission decided to suspend the siting process noting that certain waste management actions had taken place to reduce the volumes of LLW being generated within the compact.

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
NORTHEAST (later renamed **ATLANTIC**)	Connecticut[b]	1985/2001C	*see Comments*	—	—	—	State legislature terminated siting efforts in 1992 citing the availability of out-of-state disposal capacity.
	New Jersey[b]		*see Comments*	—	—	—	State siting board terminated siting efforts in 1992 also citing the availability of out-of-state disposal capacity.
	South Carolina		C	C	C	1969 C	In 2001, South Carolina legislation restricted the use of the Barnwell disposal facility to generators in the three-member Atlantic Interstate compact after mid-2008.
NORTHWEST	Alaska Hawaii Idaho Oregon Montana Utah **Washington** Wyoming	1985C	C	C	C	1965 C	The compact's regional disposal facility is the existing Richland (Washington) facility.
ROCKY MOUNTAIN	Colorado **Nevada** New Mexico	1985C	C	C	C	1965 C[c]	Since the closure of the Beatty site, the compact has contracted with the Northwest Interstate Compact to dispose of LLW at the existing Richland facility.
SOUTHEAST[d]	Alabama Florida Georgia Mississippi **North Carolina** Tennessee Virginia	1985C	*see Comments*	—	—	—	South Carolina withdrew from compact in 1995. State siting board terminated operations in 1997 because of insufficient funding. In 1999, North Carolina withdrew from the compact (GAO, 1999, p. 72). In 2000, North Carolina joined the renamed Atlantic Compact (GAO, 2004, p. 28).

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
SOUTHWESTERN	Arizona ***California*** North Dakota South Dakota	1985C	1988C	1989C	1993C	*see Comments*	From 1993–96, the Secretary of the Interior deferred making a land-transfer decision necessary to construct and operate the state-approved Ward Valley site while the Government and NAS undertook a number of technical reviews and administrative activities (see GAO,(1977). A 1999 court decision, brought on by California, found that the Federal Government was not required by Federal law to transfer (sell) the land. Since that decision, there have been no additional siting activities by the state.
TEXAS	Maine **Texas** Vermont	1998C	1987-91C	1992C	*see Comments*	—	Fort Hancock site selected by State in 1987. State court issued a permanent injunction against the selection of site for a LLW disposal facility in 1991 (Goodell and Caskey, 1991). Following its 1991 selection, 1992 license application for the Sierra Blanca site was rejected by State Court in July 1998 (LeMone et al., 2002). In 2003, the Texas legislature designated a second geographic area in Andrews County as acceptable for a new disposal facility, and the host state's regulator developed a license application process for this new facility.
UNAFFILIATED	District of Columbia New Hampshire Rhode Island Puerto Rico	*These states do not intend to build LLW disposal facilities. They will seek storage and disposal arrangements with other states.*					
	Massachusetts	n/a	*see Comments*	—	—	—	In 1995, the state hired a contractor to conduct a statewide screening process. In 1996, the process was terminated because of renewed access to the Barnwell disposal facility (GAO, 1999, p. 76).

Interstate Compact Region	Member States	Compact Formed	Select Site	Submit License Application	License Application Approved	Operate Facility	Comments
UNAFFILIATED (continued)	**New York**	n/a	*see Comments*	—	—	—	In 1988, the state's independent siting commission conducted a multistep screening process to identify candidate sites for evaluation as LLW disposal sites. In its independent review of the site selection process, GAO (1992) found that the state did not adhere to its administrative procedures for selecting candidate sites. The Governor later suspended the siting process. In 1995, the state legislature declined to fund the siting commission (GAO, 1999, p. 76).

a. Michigan expelled from compact in 1991 for not acting in good faith to locate an acceptable disposal site. Ohio is the alternate host state.
b. Originally intended as dual host states in 1985 as part of the Northeast Interstate Compact region. In 2001, the two states, along with South Carolina, formed the Atlantic Interstate compact region.
c. The Beatty facility provided disposal service to the Rocky Mountain Interstate Compact until 1992.
d. The Barnwell site in South Carolina provided the Southeast Interstate Compact region with disposal service until 1995, at which time it withdrew from the compact.

In its 1999 review of the national LLW program, GAO (p. 5) identified some common reasons for the lack of success in providing new disposal facilities, including the following:

- the controversial nature of nuclear waste disposal and public opposition to the siting of new LLW disposal facilities
- the declining volumes of commercial LLW being generated as a result of waste minimization and processing into safer forms
- the high costs associated with siting, licensing, constructing, and operating a new disposal facility
- the continued availability of existing disposal capacity
- the consideration of alternatives to disposal (e.g., assured storage)

5 CURRENT PROGRAM STATUS

In the mid-1990s, the NRC significantly scaled back its LLW program for budgetary reasons. The actions were justified at the time because the NRC had a regulatory framework in place sufficient to review a 10 CFR Part 61 license application[33] and the Commission had relinquished its licensing authorities to those host states with a lead role in developing new commercial LLW disposal facilities. In addition, there was a lack of national progress in siting new disposal facilities.

To keep abreast of national LLW developments under the current reduced program, the staff has done several things. For example, the staff regularly monitors developments within the national program by attending regular meetings of the Low-Level Radioactive Waste Forum (or the LLW Forum).[34] The staff has also performed several specific tasks, as directed by the Commission. They include efforts to improve the transparency of NRC decisionmaking as it relates to 10 CFR 20.2002 requests[35] and to determine whether depleted uranium needs to be added to the 10 CFR Part 61 waste classification system.[36] In addition, NRC's Office of State and Tribal Programs monitored state progress in implementing LLWPAA milestones. See Combs (1992).

Consistent with earlier Congressional direction, DOE established a National Low-Level Radioactive Waste Management Program to develop and make available useful information concerning LLW management. Under contract to DOE, the operating contractor for the Idaho National Engineering and Environmental Laboratory prepared technical reports covering many LLW areas [e.g., SLB corrective measures (EG&G Idaho, Inc., 1984), LLW laws and administration (EG&G Idaho, Inc., 1985), and environmental monitoring (EG&G Idaho, Inc., 1989)].[37] From 1979 to 2000, the Department sponsored publication of annual state-by-state assessment reports that provided information on the types and quantities of commercial LLW being generated (e.g., Fuchs, 1999). In 1986, DOE developed MIMS to monitor the management of commercial LLW. This computerized data base later subsumed the annual state-by-state assessment reports series. In 2000, Congress stopped appropriating money for DOE's national LLW program with the exception of the funds necessary to maintain MIMS. In its 2004 evaluation of the national

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[33]Sections 7.4.4 and 8.1 of this report discuss the framework in more detail.

[34]Until 1985, representatives of the Governors worked to achieve the goals of the LLWPA through a committee of the National Governors' Association. After passage of the LLWPAA, representatives of compacts and states established the LLW Forum to promote the objectives of the new Federal law and the compacts. In 2001, the LLW Forum became an independent nonprofit organization.

[35]From time to time, the Commission receives requests to permit the disposal of small quantities of low-activity radioactive materials, on site, at existing NRC-licensed facilities. The NRC regulations at 10 CFR 20.2002 allow disposal exemptions to 10 CFR Part 61. Staff guidance regarding the onsite disposal of small qualitites of radioactive waste can be found in Goode et al. (1986), Neuder (1986), and Neuder and Kennedy (1987). The Commission can grant other types of disposal exemptions under 10 CFR 20.2003, "Disposal by Release into Sanitary Sewerage," 10 CFR 20.2004, "Treatment or Disposal by Incineration," and 10 CFR 20.2005, "Disposal of Specific Waste."

[36]In a decision dated October 19, 2005, the Commission directed the staff to determine whether depleted uranium produced by uranium enrichment facilities warrants consideration under 10 CFR 61.55(a) of the NRC waste classification tables. See Diaz et al. (2005).

[37]Time limitations in the development of this report did not permit a review of the DOE-sponsored technical literature.

program, GAO (pp. 14–16) found shortfalls in the quality of the MIMS data and recommended that the NRC take responsibility for generating the required reports. The GAO was particularly concerned that the unreliability of the data would make it difficult to forecast future disposal needs for all classes of LLW.

In its 1994 and 2000 reports described earlier, the GAO assessed the following three management options to respond to concerns about limited or no disposal access for commercial LLW generators:

(1) retain the existing compact approach and allow it to adapt to the changing LLW situation

(2) repeal the existing LLW legislation and allow market forces to respond to the changing LLW situation

(3) use existing DOE facilities for the disposal of commercial LLW

Most recently, in November 2005, Congress directed GAO to report on approaches to improve the management of commercial LLW within the United States. This examination is expected to include a review of international best practices (GAO, 2005b).

5.1 Recent Disposal Facility Developments

An order of the state's Governor permanently closed the Beatty LLW disposal site in 1992. The site is currently operated as a RCRA and polychlorinated biphenyl (PCB) waste disposal facility. The nation's only remaining disposal facilities are at Barnwell, Richland, and Envirocare. Only the Envirocare facility receives mixed LLW. The Barnwell facility presently receives Class A, B, and C LLW. In 2000, the South Carolina Legislature restricted disposal access to the facility to members of the Atlantic Interstate Compact after mid-2008. In 2001, the State of Utah regulatory authority approved a license amendment to allow the Envirocare facility to dispose of Class B and C LLW. However, state law requires the approval of the legislature and Governor before Class B and C waste can be received (GAO, 1994, p. 33). In late 2005, the Governor voiced his opposition and placed a moratorium on the acceptance of these wastes. With the imminent closure of the Barnwell site, there is growing concern about access to disposal facilities especially for Class B and C LLW (GAO, 2004). To address the pending shortfall in commercial disposal capacity, the GAO (2004, p. 42) proposed using existing DOE facilities for LLW disposal, as is currently the case for HLW, TRU waste, and GTCC waste.

Other disposal development activities are underway but these are taking place outside of the LLWPAA framework and focus mostly on non-Part 61 types of waste. Some notable examples include the following:

- In February 2001, U.S. Ecology acquired an existing RCRA Subtitle-C disposal facility in Owhyhee County, Idaho, near Grand View, from Envirosafe Services of Idaho. (The facility received interim RCRA authorization first in 1980, followed by formal authorization in 1988.) Shortly thereafter, U.S. Ecology sought approval from the Idaho Department of Environmental Quality to modify the existing Grand View RCRA permit to receive commercial NARM, NORM, and certain NRC-exempt items and devices.[38] The approved site permit now

[38]NRC's regulations at 10 CFR Part 30 and 10 CFR Part 40 allow for both general and specific disposal exemptions, upon application to the Commission, for certain products, devices, or items containing small amounts of low-activity radioactivity.

allows radiologically-contaminated waste from NRC or NRC Agreement State licensees to be disposed of if the material has been specifically exempted from regulation according to a clearly described set of waste acceptance criteria established by U.S. Ecology and approved by the state.[39] This permit change has also expanded commercial disposal options available to the Army Corps of Engineers (or the Corps) for some of its FUSRAP waste[40], and the site is now a major recipient of these wastes. Since 2001, the Grand View facility has received about 16,200 ft^3 (459 m^3) of FUSRAP waste and about 9700 ft^3 (275 m^3) of non-FUSRAP NORM (National Research Council, 2006, p. 70). About 160 acres of the 1250-acre Grand View site are used for disposal operations.

- In 2003, Texas law-makers passed legislation that allows private interests to apply for an NRC Part 61 LLW disposal site license (Lauer, 2003, p. 13). In response to the new law, on August 4, 2004, Waste Control Specialists (WCS), LLC, submitted a license application to the Texas Commission on Environmental Quality (TCEQ) for authorization to construct a near-surface LLW disposal facility in Andrews County, Texas. The WCS site is located on a 14,400 acre tract with more than 1340 acres currently permitted to treat and dispose of RCRA waste and Toxic Substances Control Act materials. The Andrews WCS site is also permitted for GTCC LLW storage, PCB-contaminated waste treatment, storage and land disposal, AEA Section 11e.(2) waste[41] storage, and NRC exempt and exempt-mixed waste land disposal, including selected NORM waste. TCEQ has reviewed the Andrews WSC license application and found it to be complete. Public hearings are the next step in the license application review process. If approved by the state, the new Andrews County disposal facility would receive commercial LLW from generators within the Texas LLW Compact system as well as the Government-owned LLW from DOE. The Andrews WSC site is the only commercial LLW disposal facility under consideration in the United States at this time.

- In April 2006, the Colorado Department of Public Health and Environment (CDPHE) issued a radioactive materials license amendment to the Clean Harbors Deer Trail Facility, an industrial hazardous waste landfill. Colorado regulatory authorities have in the past allowed some radioactive materials to go to industrial solid waste landfills on a case-by-case basis, after reviewing a site-specific risk assessment and the facility design and operating procedures. The license amendment authorizes the receipt, possession, processing and

[39]The conditions concern both the concentration and total quantity of specific radionuclides to be disposed of. See *http://www.americanecology.com/pdf/grandview/USEI_WAC.pdf,* dated May 4, 2005.

[40]FUSRAP refers to the "Formerly Utilized Sites Remedial Action Program." FUSRAP sites are privately held sites that have contaminated soils and structures from the refining of radium and Cold War uranium and from bomb development in the 1950s and 1960s. Although FUSRAP waste contains very low concentrations of radioactive materials, there are large volumes of such waste. The Corps is responsible for managing the FUSRAP program. No FUSRAP waste is generated from the operation of commercial power plants.

[41]Defined in Section 40.4 of 10 CFR Part 40 as "tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content...."

disposal of NORM and TENORM. The license also authorizes disposal of wastes containing or contaminated with naturally occurring radionuclides with a maximum concentration of 2000 picocuries per gram (pCi/g). The specific radium-226 maximum concentration is limited to 400 pCi/g. The license prohibits the acceptance of source material, waste that is greater than 0.05 percent by weight uranium and/or thorium (Tarlton, 2006). The Deer Trail facility is the only permitted hazardous waste disposal site in the state.[42]

5.2 Assured Storage

At the time the LLWPA was passed in 1980, it was expected that the states and Compacts would establish additional LLW disposal capacity and there would be little need for the continued storage of wastes on-site by licensees. To ensure that de facto storage would not take place at generator's sites (and thereby undermine the intent of LLWPAA) as well as the need to address certain safety considerations (NRC, 1981b[43]), the NRC staff issued guidance in the form of Generic Letter 81-38 (Dircks, 1981) that stated at the time that no facility should be built to store waste for longer than 5 years under a licensee's 10 CFR 50.59 evaluation. This policy was later extended to commercial storage operations (Dircks, 1985), and fuel cycle and materials licensees (Cunningham, 1990). Later, the staff noted that no law or regulation prohibits the storage of commercial LLW for periods of time in excess of 5 years (NRC, 1994b, p. 5) although doing so could be construed as "inconsistent with current national policy" (Op cit.). When it became apparent that the LWPAA milestone dates for the development of new disposal facilities would not be met, the staff proceeded to develop a proposed LLW on-site storage rulemaking because the Barnwell facility closed to many LLW generators in the United States only later to withdraw it. See NRC (1993c). Alternatively, the Commission directed the staff to make certain proposed changes to the existing NRC storage guidance framework; but these changes were never approved as the Barnwell facility reopened at the time to all domestic LLW generators and the immediate need for updated guidance was thereby eliminated.

As an alternative to permanent (geologic) disposal, the concept of assured storage has been proposed by Newberry and others (1995). Unlike the prevailing Part 61 disposal concept, assured storage is considered by the authors to be an acceptable LLW management alternative as it calls for the indefinite storage of LLW in an assured isolation facility (or AIF) until such time that the waste no longer poses a significant radiological hazard. The AIF is envisioned to function as an engineered, above-ground monitored storage system, with an indefinite (unspecified) service life. The key difference between a 10 CFR Part 61 disposal facility and the AIF is the provision for caretaker oversight. The AIF is designed to permit the LLW in storage to decay. Waste containment structures, systems, and components are designed to permit regular inspections and maintenance. If needed, any containment feature of the AIF can be replaced if it fails (i.e. leaks). With greater emphasis on engineering and caretaker oversight, the site (geosphere) is no longer a major consideration in the performance of this type

[42] The Clean Harbors Deer Trail, LLC, facility (commonly referred to as the Deer Trail facility) provides treatment, storage, transfer, and disposal services for both hazardous and non-hazardous waste. The facility was first permitted for hazardous wastes in April 1987 by CDPHE under the authority of the Colorado Hazardous Waste Act, and it began accepting waste in July 1991. The Deer Trail facility is approximately 70 miles east of Denver, in Adams County. Clean Harbors owns approximately 5760 acres, of which approximately 325 acres comprise the operating disposal facility.

[43] Also see Siskind et al. (1985).

Table 9. Comparison of a 10 CFR Part 61 Type of Disposal Facility with an Assured Isolation Type of Storage Facility. Adopted from Newberry et al. (1996, pp. 21–22).

	10 CFR Part 61 Facility	**AIF Storage Facility**
Physical Setting	Below grade, near surface	Above grade
Disposal Mode	Trench disposal, no physical access	Concrete vaults, with physical access
Waste Packaging	Variable, no overpacks	Overpack modules
Retrievablility	Nonretrievable	Retrievable
Institutional Controls	100-year caretaker period following site closure	Indefinite, no prescribed limit
Monitoring and Remediation	Not to exceed the 100-year caretaker period following site closure	Indefinite
Reversibility	Disposal essentially permanent	Options open

LLW management system. See Table 9. Hence, the need for detailed site characterization, complex performance assessment analyses, and the development of a long-lived waste package needed to achieve disposal is obviated, with a net cost savings to waste generators.

In a September 2002 Staff Requirements Memorandum (SRM), the Commission directed the NRC staff to explore interest in the assured isolation concept and develop a rulemaking plan that could be used to provide a foundation for a Commission decision on whether to develop such a rule (NRC, 2002). The need for a rulemaking plan was prompted by the development of a draft AIF regulation by the State of Ohio, and the state's subsequent request for NRC to review and comment on that draft regulation. At the time, at least 5 other states were contemplating similar regulations. The Ohio rule (Ohio Department of Health, 2003) is now the only AIF regulation currently in effect; however, the regulation has never been implemented by the state. In a 2005 study, the Midwest Interstate LLW Compact questioned the need for an AIF. See Illinois Emergency Management Agency (2005). In a 2005 review of DOE's LLW management programs, the GAO (2005a) recommended the use of life-cycle cost analyses to evaluate competing LLW management alternatives.

For its part, the NRC has no regulations or criteria for the design and operation of an AIF. To ensure consistency with any future state regulations, the staff has previously recommended the development of an AIF rule. However, before proceeding to develop such a rule, the staff surveyed the states, Interstate Compacts, and industry representatives to determine how widespread the support was for an NRC regulation in this area; responses to that survey suggested only limited interest. See NRC (2003). Should NRC promulgate an AIF regulation, Ohio and any other states with similar regulations would be required to modify those regulations to be consistent with NRC's, based on the Commission's AEC authorities. In a January 2004 SRM, the Commission has directed the staff to defer action on the development of an AIF rule and annually review the need for further action in this area (NRC, 2004).

For its part, EPRI has published recommendations on the management and interim storage of commercial LLW. See EPRI (1994, 2002).

The staff intends to revisit this issue as part of its 2006 strategic planning initiative. See NRC (2006c).

5.3 Low-Activity Radioactive Waste

Some radioactive waste streams, by legal definition, are not SNF, HLW, TRU, or LLW. Low-activity radioactive waste can occur in concentrations greater than background levels, but less than Class A materials, which have no specified lower limit.

In 1975, Gesell and Prichard noted that certain human activities can result in the unintentional yet anomalous concentration of naturally occurring radioactivity to levels greater than those found in the environment. They cited radiation emissions from coal-fired power plants, radon in harvested natural gas, radium in manufactured fertilizer, radium in processed drinking water, and enhanced cosmic ray exposure in high-altitude aircraft as examples of these anomalous concentrations. Because of the potential for significant occupational or population exposures above background levels, Gesell and Prichard recommended that a new category of radiation exposure be recognized - technologically enhanced natural radiation (TENR) - to permit evaluation of the incremental health risk of LAW (although not defined as such at the time).[44] Accelerator-produced radioisotopes were later added to the unofficial definition, now renamed technologically enhanced naturally-occurring radioactive materials (TENORM). Other slightly contaminated (short-lived) radioactive materials, generated from the decommissioning of NRC-licensed facilities, including nuclear power reactors (National Research Council, 2002), are now generally considered part of the LAW spectrum.

According to past EPA (1988, p. 3-21) estimates, as many as 70 potential sources of LAW could exist. Although existing commercial LLW disposal sites can accept LAW for disposal, the management of these waste streams has gained increased attention in recent years because of the substantial volume of material they represent, estimated to be on the order of 10^9 ft^3 (10^7 m^3) annually (EPA, 2000a, p. 2) compared with 10^5 ft^3 (10^3 m^3) of LLW generated annually (NRC, 2001a, p. 3). However, a comprehensive regulatory framework to guide the management of these non-AEA materials does not exist. A complex patchwork of regulations, some Federal, but mostly state, applies to these wastes. In general, this framework is based more on the generation (source) of LAW rather than on its radiologic hazard or health risk. The question has thus been raised from time to time as to whether greater Federal responsibility is needed for the management of LAW to ensure a consistent integrated approach to controlling human exposures to such materials commensurate with the health risks.

As early as 1974, NRC Agreement States recommended that the AEC (or its successor) undertake the overall responsibility for regulating LAW (Lacker, 1974). In response, NRC staff periodically reviews the matter. See Nussbaumer et al. (1977), Bolling et al. (1984), and Austin (1988). Following these reviews, SECY papers issued April 1978 (NRC, 1978a), December 1978 (NRC, 1978c), March 1988 (NRC, 1988a), and September 1992 (NRC, 1992d) made staff recommendations to the Commission on whether it should seek to extend the NRC's statutory authority in this area. In September 1996, as part of its Strategic Planning Framework (NRC, 1996d), the staff identified options for the Commission to consider for whether to continue to regulate or to revise its oversight of the medical uses of nuclear byproduct materials

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[44] LAW is unofficially defined to include low activity materials defined as NORM, NARM, and TENORM. See Appendix B to this report for an expanded discussion of LAW.

including NARM.[45] On each occasion, though, the Commission has decided not to seek an expanded statutory authority to include LAW. See NRC (2006a).

Citing inadequate regulatory coverage, the Conference of Radiation Control Program Directors (CRCPD) began to develop "suggested" state regulations for LAW (specifically TENORM) in the 1980s. Although the recommendations have no legal authority, the proposed regulations, issued in December 1999, are intended to serve as a model for future state regulations. The suggested regulations (CRCPD, 1999a) were supported by a rationale (technical basis) document (CRCPD, 1999b) and implementing guidance (CRCPD, 2004). In its proposal, the CRCPD recommended that companies which possess, use, manufacture, or make products or wastes in which the radium-226 content is greater that 5 pCi/g would require licensing.

In 2002, the NAS initiated a review of the regulatory and guidance framework for managing LAW at the request of 10 Federal, state, and foreign organizations.[46] The NAS issued an interim report in late 2003 (National Research Council, 2003) and a final report in 2006. In its final report (National Research Council, 2006), the NAS investigating committee found that certain categories of LAW had not received consistent regulatory oversight and management, and, for those categories that were regulated, the regulations were not commensurate with the hazard posed by the waste. Consequently, the NAS recommended that a more "risk-ba sed approach" (e.g., Kaplan and Garrick, 1981) for the management of LAW to be undertaken through an integrated, incremental process.

With the passage of the Energy Policy Act of 2005 (Public Law 109-58), Congress decided to extend NRC control over some types of LAW, specifically, concentrated yet short-lived NORM and NARM waste residues. The act amended Section 11e. of the AEA to include certain types of NARM. However, this extended authority did not address the diffuse, more abundant sources of LAW. In response to the new Congressional direction, the Commission is currently reviewing the proposed rule package and will be voting on it at a later date. See NRC (2006b).

For its part, EPA attempted to develop radiation standards for the management of LAW in the 1980s in parallel with the development of LLW radiation standards. The EPA proposed LLW and NARM regulations (EPA, 1983a) never cleared the Federal interagency review process. (See Appendix B of this report.) However, more recently, EPA has undertaken several regulatory initiatives to address the management of mixed LAW. See EPA (2003).

5.4 Stakeholder Views

In addition to the national program reviews by the GAO and OTA, some LLW stakeholder organizations and entities have prepared position papers expressing their views on various matters related to the management of commercial LLW. Some of these position papers also call for changes to the NRC's LLW regulatory framework. An Internet search summarized in Table 10 indicates that there are several published position papers. These position papers provide different perspectives and sometimes conflicting stakeholder positions on the issues. No attempt has been made to summarize the

[45]Direction-Setting Issue 7 discussed five options, including an expanded regulatory responsibility for x-ray, accelerators, and NARM.

[46]Sponsoring organizations included the Corps of Engineers, the California Environmental Protection Agency, the U.S. Department of Defense, DOE, EPA, the Japanese Institute of Applied Energy, the French Institute de Radioprotection et de Sureté Nucléaire, the Midwest Interstate LLW Compact, the NRC, and the Southeast LLW Compact Commission.

Table 10 Stakeholder Position Papers Concerning LLW Management

Organization/Entity	Internet Homepage	LLW Policy Statement	
		Title	Date
American Nuclear Society	*http://www.ans.org/*	"Disposal of Low-Level Radioactive Waste – Position Statement No. 11"	November 2004
Association of Media Accuracy	*http://www.nuclearpowerprocon.org/pop/Wastes.htm*	"Nuclear Energy-– Storage, Disposal and Transportation of Radioactive Wastes" (includes a discussion of LLW)	No date
California Radioactive Materials Management Forum (Cal Rad Forum)	*http://www.calradforum.org/*	"A National Solution for a National Problem"	2003
Council on Radionuclides and Radiopharmaceuticals (CORAR)	*http://www.corar.org/*	"Council on Radionuclides and Radiopharmaceuticals Position Paper on Low-level Radioactive Waste Disposal"	April 6, 2001
Health Physics Society	*http://www.hps.org/*	"Low-level Radioactive Waste Management Needs a Complete and Coordinated Overhaul"	September 2005 (revision)
League of Women Voters	*http://www.lwv.org//AM/Template.cfm?Section=Home*	"Environmental Protection and Pollution Control" (general subject of LLW management)]	July 5, 2005
LLW Forum	*http://www.llwforum.org/*	"Management of Commercial Low-Level Radioactive Waste"	September 22, 2005
National Governor's Association	*http://www.nga.org/portal/site/nga*	NR-19 Policy Position, "Low-Level Radioactive Waste Disposal Policy"	February 26, 2004
National Mining Association	*http://www.nma.org/*	"The National Mining Association's and the Fuel Cycle Facilities Forum's White Paper on Direct Disposal of Non-11e.(2) Byproduct Materials in Uranium Mill Tailings Impoundments" (includes a discussion of LLW)	No date
Nuclear Information and Resource Service	*http://www.nirs.org/factsheets/llwfct.htm*	"Low-Level Radioactive Waste"	March 1992
Sierra Club	*http://www.sierraclub.org/nuclearwaste/low.asp#A%20Responsible%20Response*	"Low-Level" Radioactive Waste (LLRW) Management"	No date
Southeast Interstate LLW Compact	*http://www.secompact.org/*	"Management of Low-Level Radioactive Waste"	November 30, 2005

opinions expressed. The reader is referred to the individual papers to better understand the respective views of the organizations that have prepared these papers.

PART II. THE NRC'S LOW-LEVEL RADIOACTIVE WASTE REGULATORY FRAMEWORK

6 INTRODUCTION

Without exception, all past case studies of LLW disposal pointed to the need to improve its management to ensure that the wastes, once disposed of, would not create a public health hazard. This meant not only protecting workers and the public during the operational phase of waste disposal, but also assuring that once a facility was closed, the disposal "system" would contain the waste for a period of time sufficient to ensure that it no longer posed a hazard.

In response to the needs and requests of the public, the states, industry, and others, the Commission promulgated specific requirements for licensing the near-surface land disposal of commercial LLW at 10 CFR Part 61. These requirements were developed during a 5-year period from 1978 to 1982, following the 1977 recommendations of an internal NRC task force (NRC, 1977d). The Commission published its final commercial LLW disposal regulation in the *Federal Register* on December 27, 1982 (47 FR 57446). The rule applies to any near-surface LLW land disposal technology. This includes SLB, engineered land disposal methods such as below-ground vaults (BGVs), earth-mounded concrete bunkers (EMCBs), and augered holes. The regulation emphasizes an integrated systems approach to commercial LLW disposal, including consideration of site selection, disposal facility design and operation, minimum waste form requirements, and disposal facility closure. To lessen the burden on society over the long periods of time contemplated for the control of radioactive material, 10 CFR Part 61 emphasizes passive rather than active systems to minimize and retard releases to the environment. Various subparts of the rule cover general provisions and procedural licensing aspects, while other subparts cover the performance objectives; financial assurances; state and tribal participation; and records, reports, tests, and inspections. The NRC did not require existing LLW disposal sites to conform to the 10 CFR Part 61 requirements, although many of the features of the regulation were incorporated as license conditions for existing facilities.

Since 1983, the NRC staff has developed several documents intended to aid in the implementation of 10 CFR Part 61. Foremost among these are NUREG-1300, " Environmental Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility (Environmental Report)" (Pangburn et al., 1987); NUREG-1199, "Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility" (NRC, 1991a); and NUREG-1200, "Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility" (NRC, 1994a). NUREG-1199 details the components and information required by 10 CFR Part 61 for a license application for an LLW disposal facility. NUREG-1200 provides guidance on the process that the staff would use to review a 10 CFR Part 61 license application. Consistent with the requirement in the LLWPA to review a 10 CFR Part 61 license application within 15 months of its receipt, the staff prepared NUREG-1274, "Review Process for Low-Level Radioactive Waste Disposal License Application under Low-Level Radioactive Waste Amendments Act" (Pittiglio, 1987), which describes the NRC's approach to reviewing license applications. To enhance the staff's capability to review and evaluate license applications within the required 15-month timeframe, the staff also developed a LLW performance assessment program plan. See NRC (1992a).

In issuing a 10 CFR Part 61 LLW disposal facility license, the NRC would be required to prepare an EIS. NRC Regulatory Guide 4.18, "Standard Format and Content of Environmental Report for Near-Surface Disposal of Low-Level Radioactive Waste" (NRC, 1983d), and NUREG-1300 (Pangburn et al., 1987) guide the staff as to what to include in the EIS. Because of the key role quality assurance (QA) has played in the nuclear program, the NRC staff has also developed specific QA guidance for the LLW regulatory arena. NUREG-1293, "Quality Assurance Guidance for a Low-Level Radioactive Waste Disposal Facility" (Pittiglio and Hedges, 1991), provides specific guidance on how to meet the 10 CFR Part 61 requirements.[47] NUREG-1383, "Guidance on the Application of Quality Assurance for Characterizing a Low-Level Radioactive Waste Disposal Site: Final Report," (Pittiglio et al., 1990) provides QA guidance related to site characterization activities. Chapter 9 of both NUREG-1199 and NUREG-1200 provides additional QA guidance for potential 10 CFR Part 61 applicants.

Section 8 of the LLWPA, as amended, also directs the NRC to identify and publish technical information for disposal methods other than SLB. The NRC complied with this requirement by publishing NUREG-1241, "Licensing of Alternative Methods of Disposal of Low-Level Radioactive Waste - Branch Technical Position" (Higginbotham et al., 1986), and the NUREG/CR-3774 series, "Alternative Methods for Disposal of Low-Level Radioactive Wastes" (Bennett et al., 1984; Bennett, 1985; Bennett and Warriner, 1985; Miller and Bennett, 1985; Warriner and Bennett, 1985). In addition, the NRC revised NUREG-1199 and NUREG-1200 to address disposal in BGVs and EMCBs.

[47]The criteria described in NUREG-1293 are similar to the criteria contained in Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," to 10 CFR Part 50. Although Appendix B to 10 CFR Part 50 is not applicable to the NRC's LLW disposal regulation, the criteria it contains are basic to any nuclear regulatory QA program.

7 APPROACH TO DEVELOPING 10 CFR PART 61

Before the promulgation of 10 CFR Part 61, no national or international standards defined what level of safety was necessary to protect the public from disposed LLW. The only comparable regulations in place that defined "safety" were the AEC generic criteria, found at 10 CFR Part 20, which related to occupationally exposed workers during the operation of licensed nuclear facilities. These criteria define the maximum permissible levels of radiation in unrestricted areas. Although 10 CFR Part 20 does not contain technical criteria or standards specific to the disposal of licensed materials such as LLW, it was nevertheless used to license early LLW disposal facilities because the regulation was generally intended to protect both workers and members of the public.[48]

Consistent with the staff's 1977 Program Plan (NRC, 1977d), the Commission published an ANPR, in October 1978, inviting advice, recommendations, and comments from stakeholders on the scope of the EIS the staff was developing in support of the new 10 CFR Part 61 regulation (NRC, 1978b). The proposed EIS was not intended to be a generic EIS on LLW disposal vis-a-vis the NEPA process. Rather, it was intended to serve as the document that would provide the bases and record for Commission decisions on the requirements to be set out in the forthcoming regulation. To ensure that no viable LLW disposal alternatives would be overlooked, as part of the scoping process, the NRC sponsored a technical study (Macbeth et al., 1978) that was included as part of the 1978 ANPR. Also see Denham (1988).

The Commission used the comments received during the ANPR to scope and form the content of NUREG-0782, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes" (NRC, 1981c), as well as the preliminary draft regulation which became available for public comment on February 28, 1980 (45 FR 13104). The draft regulation identified the licensing procedures, performance objectives, and technical requirements necessary for the licensing of commercial LLW disposal facilities. The proposed regulation also reflected the NRC's longstanding ALARA or "as low as reasonably achievable" regulatory principles (The White House, 1987).[49] During the summer and fall of 1980, the Commission also sponsored four regional workshops to give stakeholders an opportunity to discuss the issues addressed in the proposed 10 CFR Part 61 rulemaking. The Commission received 36 comments from the public on the ANPR. The respondents strongly supported the Commission's development of specific standards and criteria for the disposal of LLW (NRC, 1981b). Among the comments received were specific recommendations that a system was needed for classifying or segregating

[48]This section provides some general background on the approach used to develop 10 CFR Part 61 and, in doing so, highlights a few key issues considered important at the time. This summary is not intended to be exhaustive. NUREG-0782 (NRC, 1981c) and NUREG-0945 (NRC, 1982a) provide a more detailed account of this development process, as well as the disposition of key issues related to that development.

[49]10 CFR Part 20 establishes standards for protection against radiation hazards arising out of NRC-licensed activities. A guiding principle for 10 CFR Part 20 is that NRC licensees make every reasonable effort to maintain radiation exposures and releases of radioactive materials as low as is reasonably achievable or ALARA [see 10 CFR 20.1101(b)]. As defined in 10 CFR 20.1003, ALARA requires that every reasonable effort be made to maintain exposures below the 10 CFR Part 20 dose limits, taking into account the state of the technology, the economics of improvements in relation to the benefits to the health and safety of the public and occupational workers, other societal and socioeconomic considerations, and the utilization of nuclear energy in the public interest. However, a review of how ALARA principles were considered and applied to the development of the 10 CFR Part 61 LLW regulation is beyond the scope of this report.

the waste based on (radiological) hazard (46 FR 38082). After considering the information received, the Commission published its proposed 10 CFR Part 61 LLW regulation on July 24, 1981 (46 FR 38081). The NRC staff and one of its technical assistance contractors, ORNL, conducted a series of three symposia between 1981 and 1983 to examine technical issues related to the siting, design, and/or performance of LLW disposal facilities, as well as the proposed draft 10 CFR Part 61 regulation. See Yalcintas and Jacobs (1982) and Yalcintas (1982b, 1983).

The Commission received comments from 107 individuals, organizations, and entities on the proposed regulation and considered the general response to the proposed rule to be favorable (47 FR 57447). For the most part, the comments were evenly split, either explicitly supporting the rule and the Commission's proposed overall regulatory approach, or offering constructive comments on specific aspects of the proposed rule without taking a general position on the rule itself, or offering support with reservations. No state group or existing LLW disposal site operator expressed opposition to the proposed rule. Only 15 commenters expressed outright opposition to the rule or some significant portion of it. As a result of the generally favorable comments received, the Commission finalized 10 CFR Part 61 in 1982 (47 FR 57446). To support publication of the final rule, the staff also issued NUREG-0945, "Final Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes," (NRC, 1982a), which contained a detailed analysis of the comments received on the DEIS, as well as the decision bases and staff positions in support of the final regulation. A series of independent analyses also supported the EIS.

7.1 Elements of the LLW Regulation

The 10 CFR Part 61 regulation applies to any near-surface and above-ground disposal technology for commercial LLW. The regulation covers all phases of LLW disposal from site selection through facility design, licensing, operations, closure, and postclosure stabilization, to the period when active institutional controls end. The regulation also establishes the procedures, criteria, terms, and conditions that the Commission would use to issue and renew existing licenses. The requirements emphasize an integrated systems approach to LLW disposal, including consideration of site selection, site design and operation, waste form, and disposal facility closure. Because of the long periods of time contemplated for the control of radioactive material, 10 CFR Part 61 also emphasizes passive rather than active systems to minimize and retard releases to the environment. To provide flexibility in siting and designing disposal facilities, the Commission devised an LLW classification system based on the half-lives and concentrations of radioactive materials that are expected to be in the wastes. All commercial LLW classes are subject to minimum waste form characteristics.

The 10 CFR Part 61 regulation is organized into several subparts. Various subparts cover general provisions and procedural licensing aspects, while other subparts cover the performance objectives; financial assurances; state and tribal participation; and records, reports, tests, and inspections. In addition, the regulation specifies requirements that the waste generator must meet, including requirements for waste form and content, waste classification, and waste manifests. See Appendix C to this report for more details on major subject areas in the regulation.

As noted previously, the 10 CFR Part 61 regulation focuses on the long-term disposal of commercial LLW. The Commission employed a top-down, integrated systems approach to developing the regulation. It proposed performance goals (objectives) that accounted for both short-term and long-term radiological exposures. The regulation was oriented towards overall performance objectives that define the safety goals (regulatory policies) to be achieved in waste disposal. (See next section of this report.) The performance objectives are supported by a narrow (minimum) set of prescriptive technical standards that, based on past operating experience, are judged to be important to meeting the overall performance objectives. The intent of this regulatory approach was to give flexibility to LLW disposal facility developers, consistent with a particular geologic and/or geographic setting, in choosing advantageous siting and design features and operating practices necessary to achieve the performance objectives (46 FR 38083). The Commission chose not to include too much specificity in the technical standards as that would require considerable detailed knowledge about the spectrum of designs, techniques, and procedures for disposing of commercial LLW. Alternatively, the Commission chose to provide prospective applicants with flexibility in deciding how they would meet the performance objectives.

Through the earlier scoping process, the site (geosphere) was considered to be part of the containment system which, in concert with specific design features (e.g., clay liners, engineered barriers), would slow the expected release of LLW to acceptably small quantities of radioactive material over time. The technical requirements apply to site suitability, specific features of the facility design, operations and closure, waste classification, waste form, and certain institutional assurance measures. Requirements for environmental monitoring in the postclosure phase would ensure the assessment of the overall system's performance. Based on past reviews and experience, the Commission deemed these minimum technical requirements collectively important to achieving successful waste disposal. Because there are multiple barriers (including a stabilized waste form), reliance is not placed on any one component of the LLW disposal system to ensure that the performance objectives are met. Rather, all components of the system, acting in concert, are intended to contain and isolate the wastes. This concept of multiple barriers is consistent with the Commission's traditional views regarding defense-in-depth[50] and aids in the decisionmaking for issuing a 10 CFR Part 61 license using the standard of "reasonable assurance."[51]

[50]"Defense-in-depth" is more of an NRC design principle and operational philosophy than a regulatory requirement per se. A review of the literature indicates that there is no official or preferred definition (Sorensen et al., 1999, p. 1). One of the essential features of the principle is the concept of employing successive compensatory measures to prevent accidents or mitigate damage if a malfunction or accident occurs. (As applied to a disposal system containing LLW, the compensatory measures would be multiple physical barriers that provide redundancy in containment.) The net effect of incorporating defense-in-depth into design, construction, maintenance, and operation is that the facility or system tends to be more tolerant of internal failures and external changes. As applied to the NRC's regulatory programs, this principle is discussed in more detail in NRC (1983c, 48 FR 28196–28197), NRC (1998b), and Powers (1999).

[51]Section 61.23, "Standards for Issuance of a License," of Title 10 of the *Code of Federal Regulations* defines the standards the Commission will use to determine if it can issue a 10 CFR Part 61 license application to operate an LLW disposal facility. In issuing any license, the Commission would apply the standard of reasonable assurance. Historically, the Commission has used the concept to describe the acceptability of information submitted in a license application that would demonstrate that the licensed facility would perform as intended and, in doing so, protect public health and safety. The Commission, at 48 FR 28204, describes how it would use the standard in the context of 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," the NRC's generic geologic disposal regulations for SNF and other HLW. See also Schweitzer and Sastre (1987, pp. 4–5).

7.2 Who Should Be Protected and What Should the Level of Protection Be?

As noted earlier, the Commission's intent in promulgating 10 CFR Part 61 was to develop a regulation that addressed all phases of the LLW disposal cycle. This meant that the regulation had to be sufficient to cover disposal operations and closure, as well as the long-term period of waste isolation.

The Commission developed the performance objectives defined in Subpart C expressly for commercial LLW.[52] They define the overall level of safety to be achieved by disposal. Although the Commission's requirements in 10 CFR Part 20 were considered appropriate for existing types of nuclear facility operations, they were not considered appropriate for the long-term disposal of LLW (NRC, 1989c, p. 7). The 10 CFR Part 61 performance objectives are intended to provide protection from normal disposal facility operations as well as longer term protection from the release of radioactive materials after facility closure, including accidental exposures caused by inadvertent human intrusion and waste exhumation, in which the intruder is unaware of the presence of the disposal site. The technical requirements in Subpart D are minimum requirements intended to help ensure compliance with the performance objectives.

The Commission was also concerned about the potential for inadvertent human intrusion once institutional control of the site had ended and knowledge of the hazard ceased. Near-surface disposal raises the possibility of exposures to ionizing radiation resulting from man's efforts to reclaim a disposal site for productive use such as farming, housing, or natural resource development. Archeological activities and scavenging could also lead to waste exhumation. The staff recognized early in the EIS scoping process that because these behaviors could not be predicted, there was no way to guarantee that inadvertent human intrusion at the site would not occur at some point in the future (46 FR 38083). Consequently, the staff determined that future generations, in effect, should be afforded the same level of protection as the general population today. Although widely used today in the evaluation of radioactive waste disposal systems,[53] the human intruder scenario was a unique concept when the Commission first proposed it.

In another type of intergenerational equity concern, the Commission took the position that future generations should not bear the responsibility for managing wastes produced by past generations. The Commission stated that the disposal facility, its components, and even certain types of LLW should be robust (physically stable) and recognizable for some minimum period of time into the future while the radiological hazard still exists so as to preclude the potential for releases into the environment (NRC, 1982b, 47 FR 57457, 57459).

As a result of these considerations, during the rulemaking scoping process, the Commission proposed the following performance objectives found in Subpart C:

- Protect members of the public (at 10 CFR 61.41, "Protection of the General Population from Releases of Radioactivity").

[52] In the absence of applicable environmental radiation standards promulgated by EPA, the NRC developed the four performance objectives through rulemaking. See Section 7.4.2 of this report for further information.

[53] By evaluating the disruptive consequences of borehole drilling, the robustness of radioactive waste disposal designs to human intrusion scenarios can be evaluated. For example, see Charles and McEwen (1991), Nuclear Energy Agency (1991), Berglund (1992), and Wescott (2001).

- Protect inadvertent human intruders entering the facility once disposal operations have ceased and the facility has been decommissioned (at 10 CFR 61.42, "Protection of Individuals from Inadvertent Intrusion").

- Protect occupationally exposed workers during facility operation (at 10 CFR 61.43, "Protection of Individuals during Operations").

- Assure the long-term physical stability of the disposal facility to obviate the need for long-term maintenance after decommissioning of the facility (at 10 CFR 61.44, "Stability of the Site after Closure").

These performance objectives effectively defined the Commission's policy on who would be protected (and when) as the result of the operation of a commercial LLW disposal facility. The first performance objective applied to short-term exposures associated with the preclosure phase of facility operations. As noted earlier, the intent of this requirement was to ensure that LLW disposal facilities would be operated in conformance with the same standards for radiation protection that the Commission already applied to existing nuclear materials licensees. As a consequence, this performance objective required compliance with existing 10 CFR Part 20 criteria for radiation exposure to workers.

With the update of 10 CFR Part 20 (NRC, 1991c), there are now two different bases for doses in 10 CFR 61.41 and 10 CFR 61.43. The whole-body and organ dose limits specified in 10 CFR 61.41 are based on the older system of dose calculation methods as documented in the International Commission on Radiological Protection (ICRP) Publication 2 (ICRP, 1959). This system is based on the principles of maximum organ burdens and intakes so annual doses are limited to the maximums allowed for critical organs. Currently, 10 CFR Part 20 is based on ICRP Publications 26 and 30. See ICRP (1977 and 1979–88,[54] respectively). The principles in these reports are based on estimating doses for 50 years for intakes that occur in a year of practice and limiting exposures so that the assigned dose for intakes in that year does not exceed limits.

The practical result is that under the new system, long-lived radionuclides are more restricted than under the old system. In short, a dose expressed in mrem/yr to the whole body using the concepts in 10 CFR 61.41 is not necessarily equivalent to 25 mrem total effective dose equivalent (TEDE) assigned to a year of practice using the concepts in 10 CFR Part 20. The difference is greater if more long-lived radionuclides are involved in internal exposures.

Although appropriate for the preclosure phase of operations, the Commission did not consider 10 CFR Part 20 adequate for the postclosure phase, as the manner, the timing, and the nature of potential radioactive releases for specific types of LLW would be more difficult to predict under any scenario - natural or otherwise - for any particular repository design. The determination of what specific technical requirements might be needed to achieve safety during the postclosure phase required a more definitive assessment of the potential radiological hazard. To conduct this assessment, the Commission postulated two logical exposure scenarios, (a) an event in which radioactive material is transported off-site (i.e., ground-water migration) as a result of the natural evolution of the disposal system and its environs (this is now commonly referred to as the undisturbed or "base case" scenario) or (b) a potential event similar to the one already described above in which individuals come into

[54] ICRP Publication 30 was issued in four parts between 1979 and 1988. See ICRP (1979, 1980, 1981, 1988). Including indexes and supplements, eight volumes are associated with the Publication 30 series.

unintentional, direct contact with the buried waste (this is now commonly referred to as a disturbed or "human intrusion" scenario).

The Commission thus intended the remaining three performance objectives (Sections 60.42, 60.43, and 60.44) to address potential long-term exposures that might be encountered during the postclosure period of the disposal facility life cycle. In proposing these performance objectives (and the supporting technical requirements), the Commission recognized that the period of greatest reliance on the disposal system would be long after the facility had been closed as some LLW can remain hazardous for many hundreds if not thousands of years. Because of the potential for humans to inadvertently enter a disposal facility and come into contact with radioactive waste, the Commission quickly recognized that, when taking into account the long timeframes of concern, the intruder scenario would likely be the key scenario driving decisions on what combination of siting and design requirements was necessary to provide sufficient protection to ensure the safety of the public and the environment.[55]

7.3 10 CFR Part 61 Scoping Activities

Based on the review of the past performance of some commercial and Federal waste disposal sites, the Commission recognized that certain LLW management practices (i.e., siting and design decisions, preferred waste forms, packaging techniques) had already produced favorable disposal outcomes. At some sites, LLW had been contained in disposal cells, and no releases of radioactive material to the accessible environment had occurred. The challenge in developing the new regulation was to understand what combination(s) of practices and/or standards could be relied on to produce the same favorable outcomes at future disposal sites. Understanding the answers to these questions would help determine what level of protection was necessary for the operation of a LLW disposal facility.

7.3.1 NUREG-0456: A Proposed LLW Dose Assessment Model

In developing the technical criteria and standards for SLB, the Commission recognized that it would need to define the concentrations and quantities of waste acceptable for disposal under an LLW regulation. This meant developing an analytical methodology that allowed the interfaces between key components of an LLW disposal system (i.e, specific siting and design features, performance objectives, and source terms) to be defined quantitatively. More specifically, for certain key radionuclides and waste forms, the staff needed to identify the existing LLW management practices and/or disposal methods that worked best in containing wastes and limiting doses.

One of the early analyses the staff conducted as part of the DEIS scoping process was the development of a generic LLW dose assessment methodology. For certain key radionuclides and waste forms, the staff sought to identify (and quantify) an optimal set of model parameters (e.g., disposal practices) that could be used to control doses. Using a consistent set of relatively simple exposure pathways, the staff proposed a deterministic dose assessment methodology in NUREG-0456, "A Classification System for

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[55] If there were complete assurance that a commercial LLW disposal site would not be subject to human intrusion, then the 10 CFR Part 61 rulemaking effort would have been reduced to determining what technical criteria were necessary to ensure that the disposed wastes would remain within the confines of the disposal facility until such time that the LLW had decayed to background levels. However, because complete assurance in this regard was not possible, the rulemaking effort needed to account for the eventuality that there would be human intrusion into a disposal site and exhumation of or contact with the wastes. The Commission recognized that specific design precautions and/or waste form specifications might be necessary to protect against the more hazardous, longer lived LLW forms, specifically Class B and C wastes (47 FR 57451).

Radioactive Waste Disposal - What Waste Goes Where?" (Adam and Rogers, 1978). It was applied to two reference disposal methods (sites) and a preliminary three-tier LLW classification system. Analysts could compare estimated dose impacts with dose guidelines developed for the study[56] to determine maximum allowable concentrations (limits) of radionuclides appropriate for each of the proposed waste classification tiers through "what-if" types of analyses.

The most likely release path of radionuclides from a near-surface disposal facility to the biosphere is transport by groundwater following dissolution of the LLW form. However, near-surface disposal facilities are also subject to exhumation by geologic processes, as well as by inadvertent human intrusion. To account for these scenarios, the dose methodology developed was the traditional release-transport-exposure-consequence model. The methodology consisted of a basic dose model, dose guidelines, exposure scenarios, and calculational basis. Analysts considered two mechanisms or exposure scenarios in which individuals could come into contact with the waste. They were the " onsite reclaimer" scenario and the "offsite transporter" scenario. The onsite reclaimer scenario considered six potential exposure pathways, while the offsite transporter scenario considered four. See Table 11. These exposure scenarios were believed to be reasonably conservative. All features of the NUREG-0456 dose methodology were deterministic. The intruder scenario was assumed to occur with a probability of one, 150 years after the end of institutional controls at the disposal site, when most of the short-lived radionuclides would have already decayed. The offsite transporter scenarios were also calculated deterministically and were assumed to be initiated immediately after the waste was disposed. In this latter scenario, there is essentially no credit for radionuclide decay, and the releases therefore can be considered instantaneous exposures.

Once developed, the overall methodology was benchmarked against existing analog sites to validate the computational features of the analysis. The analog locations selected were the Maxey Flats LLW disposal site (in Kentucky) and the Latty Avenue uranium mill tailings site (in Missouri). In addition, based on the study's dose guidelines limits, the methodology was able to provide preliminary estimates of the maximum concentrations or inventories of radioactive material in commercial LLW that were permissible to ensure that exposures did not exceed the assumed safety goals for maximum individual and total population doses. Before publication, all features of the NUREG-0456 methodology and results underwent a peer review to provide a critical, independent assessment of the work.

7.3.2 NUREG/CR-1005: A Proposed Radioactive Waste Classification System

Having defined a generic methodology for understanding the sensitivity (coupling) between key disposal system interfaces, analysts needed to move to the next phase of the EIS scoping process. This involved devising a waste classification system that would allow a correlation between the hazard posed by the waste, the safety goal to be achieved by disposal, and some prescriptive regulatory requirements necessary to achieve the safety goals. Any disposal solution must recognize that radiotoxicity and environmental mobility are key

[56] By law, EPA was responsible for the development of radiation exposure standards and criteria to be applied to LLW. However, at the time of the staff's scoping analyses, such criteria were not available. Consequently, the NRC staff postulated a reasonable set of guidelines to provide protection from the effects of ionizing radiation, based on a review of the recommendations of national and international standard-setting organizations, consistent with ICRP Publication 26 (ICRP, 1977). See Adam and Rogers (1978, pp. 6–10) and the discussion in Section 7.4.1 of this report for more information.

Table 11 **Exposure Scenarios Considered in NUREG-0456.** Taken from Adam and Rogers (1978, pp. 15–17).

Scenario	Event	Pathway	Comments
Onsite Reclaimer	Inhalation	Worker	Inhalation of contaminated dust
		Resident	
	Ingestion	Well Water Consumption	Ingestion of contaminated groundwater and/or consumption of food grown in soil irrigated with contaminated groundwater
		Food Consumption	
	Direct Exposure	Worker	Direct exposure to gamma radiation
		Resident	
Offsite Transporter	Inhalation	Continuous Operational Release	Atmospheric transport
		Accidental Release	
	Ingestion	Groundwater-to-River	Ingestion from contaminated groundwater resource
		Surface Erosion	

parameters in defining the magnitude of exposure hazards to the public.

For example, analyses from NUREG-0456 already indicated that certain disposal practices, such as increasing the timeframe when the first exposure occurs through the use of institutional (administrative) controls, can limit the magnitude of those exposures or obviate the significance of certain exposure scenarios altogether. Alternatively, burying wastes at greater depths can achieve similar dose outcomes by eliminating the potential for certain types of intruder scenarios, as well as providing some shielding of the wastes (Adam and Rogers, 1978, pp. 5-7). Hence, by focusing on the length of institutional controls and limiting the physical accessibility of the wastes, analysts were able to formulate disposal categories that indicated how specific types of waste should be treated, as well as to recommend radionuclide concentration limits for each disposal category.

Thus, in considering the importance of half-life (decay) and environmental mobility to potential dose outcomes, King and Cohen (1977) suggested that any one of the following three disposal actions could occur:

(1) The radioactive waste does not pose significant radiological health risk to the public, and the waste can be disposed of as part of the municipal waste stream.

(2) The radioactive waste does pose some level of radiological health risk to the public, and the waste needs to be confined in some controlled manner to allow limited releases to the environment at predictably low rates, consistent with levels of background radiation found in nature.

(3) The radioactive waste poses a significant radiological health risk to the public, over an extended period of time, and the waste needs to be isolated so that biologically significant releases of radioactive material to the environment (or inadvertent human intrusion) were unlikely.

Thus, for the purposes of scoping the 10 CFR Part 61 regulation, NUREG/CR-1005, "A Radioactive Waste Disposal Classification System," proposed a "what type of radioactive waste goes where" disposal classification system (Rogers, 1979). Five types of disposal solutions were proposed applicable to all types of radioactive waste. The principal considerations in defining the proposed disposal categories were the duration of institutional controls (caretaker oversight) and reclaimer accessibility (Rogers, 1979, p. 24). As previously noted, it was believed that governmental institutions could restrict public access to disposal sites and thus the potential for coming into contact with hazardous wastes if a caretaker oversight period was specified. If this oversight period were sufficiently long, potential exposures to the hazard would be reduced by virtue of the inevitable radioactive decay of the wastes. Similarly, if the wastes were buried at depths greater than those routinely reached during construction activities, this geologic "isolation" would also help to reduce potential exposures. Both considerations were key to the NRC's 10 CFR Part 61 regulatory concept.

Building on the earlier work of NUREG-0456, analysts proposed deterministic disposal concentration guides (DCGs)[57] applicable to each disposal class consistent once again with some specified safety goal. The DCGs are the front-end parameters of the dose assessment model and represent the activity of the waste available for consideration in the assessment at the time of disposal. Analysts derived the DCGs by starting with a specified dose limit and working backwards through the dose model, pathway-by-pathway, to the initiation point of the analysis. Another important interface value was the maximum average concentration (MAC), which represents the back-end of the dose assessment model. It corresponds to the radionuclide contaminant concentration found in a particular exposure pathway.[58] Both concentration parameters are expressed in units of microcuries per cubic centimeter (μCi/cm³). By using a revised dose assessment model (Rogers et al., 1979)[59], analysts demonstrated that DCGs and MACs could be used to derive a five-tier system of disposal recommendations taking into account duration of institutional controls and reclaimer exposure pathways. See Table 12. In general, the NUREG/CR-1005 analysis indicated that for higher-calculated DCGs (Table 13), additional caretaker oversight and isolation measures were needed to ensure the safe disposal of the waste. The analysis also showed that for some exposure scenarios, the MAC can be the limiting factor in the specification of a radionuclide-specific DCG. The analysis also demonstrated that by comparing potential doses with study guidelines, the waste concentrations, waste volumes, or disposal methods could be modified to provide adequate protection to the public, which is another important EIS scoping consideration.

7.3.3 NUREG-0782: The Draft LLW EIS

The last step in the rulemaking process was to prepare an EIS consistent with NEPA. As noted earlier, the purpose of the 10 CFR Part 61 DEIS was to fulfill the NRC's NEPA responsibility, as well as to demonstrate the decisionmaking process applied to the development of the LLW disposal regulation. Using the EIS process (e.g., Rau and Wooten, 1980), the NRC staff was able to evaluate the potential health impacts of LLW disposal, possible means for limiting the impacts,

[57] Because it is not practical to perform a radioisotopic survey for every type of LLW configuration, dose conversion factors for individual isotopes were developed for NUREG/CR-1005.

[58] In NUREG/CR-1005, analysts considered only four dose pathways (reclaimer dust inhalation, food ingestion from reclaimed soil, well water consumption, and direct gamma radiation), because they believed these pathways to be the most restrictive in limiting doses to receptors.

[59] Similar to or derived from the NUREG-0456 dose model.

Table 12 **Waste Disposal Classification Categories Proposed in NUREG/CR-1005.** Taken from Rogers (1979, p. 25).

Disposal Class	Institutional Control	Accessibility	Comments
A	None	No reclaimer access	Default class. No upper limit for DCGs. Understood to be deep geologic isolation.
B	150 years	No reclaimer access except well water after 150 years	Ready access to reclaimer is unlikely. Understood to represent intermediate-depth land burial (about 30 ft). Offsite-transport, well-water ingestion is controlling exposure scenario after 150 years. DCGs are from Class C and adjusted using a 150-year decay factor.
C	20 years	No reclaimer access except well water after 20 years	Ready access to reclaimer is unlikely. Understood to represent intermediate-depth land burial. Offsite-transport, well-water ingestion is controlling exposure scenario after 20 years.
D	150 years	Reclaimer access following institutional controls	Understood to represent shallow land burial (about 10 ft).
E	None	Worker/reclaimer access	Understood to correspond to a sanitary municipal landfill.

and considering these measures, the potential reduction (benefit) that could be achieved. The EIS contained an exhaustive and detailed analysis of alternatives such as disposal facility environments, waste characteristics, disposal facility designs, and operating practices.[60] Deterministically-derived doses were presented for whole body and six organs (bone, liver, thyroid, kidney, lung, and gastrointestinal tract). The NRC published its DEIS for the proposed 10 CFR Part 61 rulemaking as NUREG-0782 (NRC, 1981c). In preparing this four-volume report, the NRC followed both CEQ regulations for preparing an EIS, as well as the NRC's NEPA-implementing regulations set out in 10 CFR Part 51, "Environmental Protection

[60]In conducting the 10 CFR Part 61 DEIS scoping calculations, the staff assumed a reference disposal facility representative of existing LLW disposal facility designs and operating and management practices throughout the United States. To summarize, the staff decided that the DEIS reference design would be an SLB facility located in a humid environment characteristic of the eastern United States. The staff selected this general location because that part of the country was generating most of the LLW and thus was likely to have the largest number of disposal facilities in the future. The site had four distinct climate seasons, although the winters were considered short and mild with an average annual precipitation of about 46 inches. The reference facility covered an area of 148 acres with a disposal capacity of about 35,000,000 ft^3 (10^6 m^3). The staff assumed the disposal facility would have a 20- to 40-year operational life. At the end of operations, the disposal site would be stabilized using existing conservation practices, and the site closed and decommissioned. Following decommissioning, the NRC operating license would be terminated, and title of the site would be transferred to a government agency that would provide active institutional controls (surveillance, monitoring, and custodial maintenance) for a period of about 100 years. During this 100-year caretaker period, there would be no incidents involving inadvertent human intrusion.

Appendix F, "Description of a Reference Disposal Facility," to Volume 2 of NUREG-0782 describes in more detail the reference facility and other applicable model parameters.

Table 13 **DCGs for Waste Classes Proposed in NUREG/CR-1005.** Taken from Rogers (1979, p. xiv).

Radionuclide[a]	Waste Class [b] DCGs (in µCi/cm³)				
	A[c]	B	C	D	E
^{3}H	2.9×10^{9}	4.3×10^{5}	94	94	0.05
^{14}C	7.1×10^{6}	140	140	2.4×10^{-3}	1.2×10^{-3}
^{55}Fe	1.9×10^{10}	SA	SA	SA	12
^{66}Co	9.7×10^{9}	SA	SA	2.1×10^{6}	2.5×10^{-4}
^{90}Sr	3.6×10^{8}	38	2.4	0.02	2.3×10^{-4}
^{99}Tc	1×10^{4}	64	64	0.1	0.05
^{129}I	850	0.3	0.3	0.3	0.024
^{135}Cs	2.4×10^{3}	20	20	0.2	0.10
^{137}Cs	1.7×10^{8}	SA	SA	0.9	4.2×10^{-3}
^{235}U	41	11	11	0.03	0.015
^{238}U	6.4	SA	SA	0.03	0.015
^{237}Np	1.3×10^{4}	0.3	0.3	0.02	5.4×10^{-4}
^{238}Pu	3.4×10^{8}	SA	SA	0.4	3.4×10^{-4}
^{239}Pu	1.2×10^{6}	90	90	0.1	3.0×10^{-4}
^{240}Pu	4.7×10^{6}	810	810	0.1	3.0×10^{-4}
^{241}Pu	2.2×10^{9}	SA	SA	5.9×10^{3}	0.015
^{242}Pu	7.6×10^{4}	13	13	0.1	3.1×10^{-4}
^{241}Am	6.4×10^{7}	SA	SA	0.4	9.2×10^{-4}
^{243}Am	3.6×10^{6}	SA	600	0.3	9.2×10^{-4}
^{242}Cm	2.6×10^{10}	SA	SA	SA	0.024
^{244}Cm	6.2×10^{8}	SA	SA	130	1.5×10^{-3}

a. The list of radionuclides found in this table are not identical to those found in Table 10 of Rogers (1979, p. xiv).
b. Waste classes are defined in Table 12 of this report.
c. Specific activity (SA) of the isotope.

Regulations for Domestic Licensing and Related Regulatory Functions." The deterministic analyses in NUREG-0456 and NUREG/CR-1005 provided a generic methodology for evaluating the risks of different types of radioactive wastes and proposing disposal solutions commensurate with those risks. NUREG-0782 relied on those methodologies and integrated them into the NEPA-EIS framework necessary to support the proposed rulemaking. However, unlike the earlier analyses, NUREG-0782 considered information viewed as more representative of the types and kinds of LLW being managed at the time, as well as pervasive LLW management practices. Volume 1 of NUREG-0782 was a summary report; Volume 2 described the NEPA-required analyses. Volumes 3 and 4 of the DEIS contained the technical analyses and other supporting information that addressed the required elements of an EIS.[61]

The following sections of this report discuss two key features of the analytical framework used to evaluate the performance of a hypothetical LLW disposal facility. They are the commercial LLW streams and exposure pathways considered in the DEIS (Sections 7.3.3.1 and 7.3.3.2, respectively).

7.3.3.1 The Waste Streams Considered[62]

At the time the NRC was developing the regulation, an estimated 20,000 NRC materials licensees were producing commercial LLW in a wide variety of waste types, forms, and amounts. This LLW was not a uniform physical quantity. It contained both short-lived and long-lived radionuclides and ranged from trash that was only suspected of being contaminated to highly radioactive material such as activated structural components from nuclear power reactors. It could be in solid, liquid, or gaseous forms. See Wild et al. (1981).

For the purposes of the DEIS scoping process and analyses, the NRC staff separated existing commercial LLW into 36 distinct waste streams (Table 14). Each waste stream represented a separate type of LLW generated by a particular type of waste source and had distinct physical, chemical, radiological, and other characteristics unique to that waste stream. The staff also analyzed the isotopic content of various waste streams and then identified the most important radionuclides present in each stream for consideration in the DEIS analysis (Table 15). To allow for the required consideration of disposal impacts and alternative management options, the staff also considered the volumes of commercial waste in each stream. In developing the regulation, the Commission noted that a key safety concern was the mobility of certain long-lived radioisotopes (iodine-129, technetium-99, carbon-14, and tritium) in the environment, especially in groundwater. By defining radionuclide concentration limits for a LLW disposal facility, the Commission sought to ensure that the proposed 10 CFR Part 61 performance objectives related to groundwater would be met (47 FR 57455).

As discussed earlier, another of the Commission objectives in developing the LLW regulation was to identify existing as well as new LLW management practices and designs that could contribute to meeting the overall performance objectives. For example, certain waste forms and processing options may reduce the potential for radionuclide dissolution and subsequent biosphere transport. Consequently, the Commission decided to also consider waste form and processing options as part of the DEIS scoping analysis. It achieved this by categorizing existing commercial LLW into four waste

[61] Specifically, the purposes, scope, and need for the rulemaking action, description of the affected environment, and discussion of a preferred action, as well as consideration of alternatives, costs, and impacts.

[62] Appendix D, "Low-Level Waste Sources and Processing Options," to Volume 2 of NUREG-0782 describes in more detail the waste stream definition process.

Table 14 **Waste Streams Considered in 10 CFR Part 61 EIS Scoping Analyses.** Taken from NRC (1981c, Volume 2 , p. 3-11).

Waste Stream Group	Group Description
Group I: LWR Process Wastes	PWR Ion Exchange Resins PWR Concentrated Liquids PWR Filter Sludges PWR Filter Cartridges BWR Ion Exchange Resins BWR Concentrated Liquids BWR Filter Sludge
Group II: Trash	PWR Compactible Trash PWR Noncompactible Trash BWR Compactible Trash BWR Noncompactible Trash Fuel Fabrication Compactible Trash Fuel Fabrication Noncompactible Trash Institutional Trash (large facilities) Institutional Trash (small facilities) Industrial SS Trash (large facilities) Industrial SS Trash (small facilities) Industrial Low Trash (large facilities) Industrial Low Trash (small facilities)
Group III: Low Specific Activity Wastes	Fuel Fabrication Process Wastes UF_6 Process Wastes Institutional LSV Waste (large facilities) Institutional LSV Waste (small facilities) Institutional Liquid Waste (large facilities) Institutional Liquid Waste (small facilities) Institutional Biowaste (large facilities) Institutional Biowaste (small facilities) Institutional SS Waste Institutional Low-Activity Waste
Group IV: Special Wastes	LWR Nonfuel Reactor Components LWR Decontamination Resins Waste from Isotope Production Facilities Tritium Production Waste Accelerator Targets Sealed Sources Industrial High-Activity Waste

Abbreviations:
LWR light-water reactor
PWR pressurized-water reactor
BWR boiling water reactor
SS sources and special nuclear material
LSV liquid scintillation vial

Table 15 **Radionuclides Considered in 10 CFR Part 61 EIS Scoping Analyses.** Taken from NRC (1981c, Volume 2, p. 3-12).

Radionuclide*	Half-Life (years)	Radiation Emitted	Principal Means of Production
^{3}H	12.3	β	Fission; ^{6}Li (n, α)
^{14}C	5730	β	^{14}Ni (n, p)
^{55}Fe	2.60	γ	^{54}Fe (n, γ)
^{66}Co	5.26	β, γ	^{59}Co (n, γ)
^{59}Ni	80,000	γ	^{58}Ni (n, γ)
^{63}Ni	92	β	^{62}Ni (n, γ)
^{90}Sr	28.1	β	Fission
^{94}Nb	20,000	β, γ	^{93}Nb (n, γ)
^{99}Tc	2.12×10^{5}	β	Fission; ^{98}Mo (n,γ), ^{99}Mo (β^-)
^{129}I	1.17×10^{7}	β, γ	Fission
^{135}Cs	3.0×10^{6}	β	Fission; daughter ^{135}Xe
^{137}Cs	30.0	β, γ	Fission
^{235}U	7.1×10^{8}	α, γ	Natural
^{238}U	4.51×10^{9}	α, γ	Natural
^{237}Np	2.14×10^{6}	α, γ	^{238}U (n, 2n), ^{237}U (β^-)
^{239}Pu	86.4	α, γ	^{237}Np (n, γ), ^{238}Np β^-); daughter ^{242}Cm
^{239}Pu	24,400	α, γ	^{238}U (n, γ), ^{238}U (β^-), ^{239}Np (β^-)
^{240}Pu	6580	α, γ	Multiple n-capture
^{241}Pu	13.2	β, γ	Multiple n-capture
^{242}Pu	2.79×10^{5}	α	Multiple n-capture; daughter ^{242}Am
^{241}Am	458	α, γ	Daughter ^{241}Pu
^{243}Am	7950	α, γ	Multiple n-capture
^{243}Cm	32	α, γ	Multiple n-capture
^{244}Cm	17.6	α, γ	Multiple n-capture

* The list of radionuclides in this table is not identical to the list in Table 10 of Rogers (1979, p. xiv).

Table 16 **Waste Spectra Considered in 10 CFR Part 61 EIS Scoping Analyses.** Adopted from NRC (1981c, Volume 2, p. 3-21). Each waste spectrum represents a cross section of all waste streams that might be generated and disposed of in an LLW disposal facility.

Waste Spectrum	Description
1	This spectrum assumes a continuation of existing and some past waste management practices. Some of the LWR wastes are solidified. However, no processing was done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be present at 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. 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 are solidified in a medium with highly improved characteristics.
2	This spectrum assumes that LWR process wastes are solidified using improved solidification techniques. LWR concentrated liquids are additionally reduced in volume through an evaporator/crystallized. All LWR concentrated liquids are evaporated in 50 weight percent solids, and all LWR process wastes are solidified. 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; some streams are compacted at the source of generation, and some are compacted at the disposal facility. Liquids from medical isotope production are solidified.
3	This spectrum assumes that LWR process wastes are solidified and that further improved waste solidification agents are used. LWR concentrated liquids are first evaporated to 50 percent weight 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 the disposal site (institutional and industrial trash from small facilities). All incineration ash is solidified.
4	This spectrum assumes extreme volume reduction. All wastes amenable to evaporation or incineration with fluidized bed technology are calcined and solidified; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Waste 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 practically achieved.

"spectra" representing generic processing options to be considered. See Table 16.

7.3.3.2 The Exposure Pathways Considered

Based on a review of exposure pathways considered in earlier studies, the NRC staff selected a limited number of exposure events for evaluation in the DEIS. As stated previously, the intent was to determine which waste streams as well as which hypothetical exposure scenarios produced the highest doses. Two exposure scenarios considered: concentration-limited and activity-limited exposure pathways (or events). Concentration-limited exposure events were inadvertent human intruder exposures that resulted from the direct contact with LLW. Doses were restricted to a few individuals and were a function of the concentration of radionuclides found in the particular waste stream that the intruder came into contact with. By contrast, activity-limited exposure events were inadvertent human intruder exposures that resulted from the indirect contact with LLW. In this exposure scenario, surface water and groundwater mobilize the radioactive waste leaching from a degraded disposal facility and environmentally transport it by dispersive forces to some distant receptor location. Doses to a small population are estimated based on some estimate of total activity of the LLW inventory, in all waste streams, initially present at the disposal facility.

As noted earlier, all of the human intruder scenarios described in the DEIS were assumed to occur with a probability of one some hundreds of years following waste disposal, when governmental controls end and institutional knowledge about the LLW facility ceases. It was assumed that the probability of human intrusion was one and that the probability of intruding into Class C waste was also one (for concentration-limited exposure pathways). Further, in all cases, the conditions of intrusion, the lack of hazard recognition, and exposure routes to the intruder (or receptor) can be best characterized as bounding.

For each of the exposure scenarios studied, the staff addressed the following four potential mitigation actions in the context of the DEIS:

(1) controlling the concentrations of the radionuclides in the specific waste streams

(2) considering alternative waste form and/or waste packaging configurations

(3) evaluating the effectiveness of the duration of institutional controls

(4) examining the effects of engineered and/or natural barriers to human intrusion

Consistent with the DEIS scoping process and rulemaking objectives, the intent was to understand what effect, if any, potential mitigation actions would have on predicted dose outcomes based on expected waste streams. If effective, these actions might make reasonable regulatory recommendations to advance for the 10 CFR Part 61 rulemaking. The Commission would decide on these recommendations by identifying which exposure scenarios were the most restrictive (i.e., produced the highest doses) and then evaluating the effectiveness of the potential mitigation actions listed above in reducing the estimated doses.

Concentration-limited exposure events.[63] Three concentration-limited exposure events were considered in the DEIS. The first was an "intruder-construction scenario." For this hypothetical exposure event, it was assumed that the inadvertent human intruder constructs a house or building directly over the disposal facility footprint unaware of any potential radiological hazard. Radiation exposures to construction workers were principally from the inhalation of contaminated air and dust, and direct exposure to gamma radiation.

The second exposure event considered was an "intruder-agriculture scenario." Here the inadvertent human intruder is represented by a resident farmer who is also unaware of the LLW disposal facility. The hypothetical farmer builds a homestead within the disposal facility footprint and engages in agriculture. Radiation exposures occur through the food-ingestion pathway when food grown on contaminated soil present at the site is consumed. Additional exposure pathways to the resident farmer included inhalation of contaminated air and dust resulting from home construction and soil tilling as well as direct gamma radiation exposures from the radioactivity suspended in the soil. As was the case with the intruder-construction scenario, the intruder-agriculture exposure scenario assumes that the LLW has degraded to a form that is indistinguishable from other indigenous soils found at the site.

The last exposure event considered in the DEIS was the "intruder-discovery scenario." For this hypothetical exposure scenario, a human intruder unknowingly exhumes a LLW disposal cell, removes a waste package container, and opens the container only to abandon it shortly thereafter. Now directly exposed to the elements, the contents of the LLW waste package container

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[63] Chapter 4, "Presentation and Analysis of Alternatives - Intruder," of Volume 2 of NUREG-0782 discusses in more detail the treatment in the EIS of these three exposure scenarios.

are transported offsite by wind and/or surface water. The focus of the dose analysis is a non-occupational acute radiation exposure to members of the general public.

Both the intruder-construction scenario and intruder-discovery scenario were considered by to be acute exposure events lasting less than a year whereas the intruder-agriculture scenario was assumed to be a chronic, longer-term exposure event since it was possible that the resident farmer would live at the site for several years in order to establish the farm. The relative severity of any concentration-limited exposure event depended on the particular waste stream (spectrum) considered in the dose assessment.

Activity-limited exposure events. [64] This DEIS analysis examined potential radiation doses associated with drinking contaminated groundwater. For this exposure event, LLW was assumed to leach from a degraded disposal facility, enter the water table, and migrate beyond the disposal site boundary. Many years later, once caretaker oversight at the site ends and institutional knowledge of the site ceases, an inadvertent human intruder in search of a drinking water supply unknowingly drills a well into the contaminated aquifer or withdraws water from a stream that receives discharge from the aquifer. The entire LLW inventory present at the site provided an initial source term for the analysis. Traditional environment fate and transport numerical methods (e.g., Codell et al., 1982) were used to estimate temporal concentrations of radionuclide in the contaminant plume.

Unlike the concentration-limited exposure events, whose dose assessments were limited principally to locations (and individuals) within the disposal facility footprint, the dose assessments for the activity-limited exposure events included receptor locations beyond the disposal site boundary and considered both individuals and small populations. See Table 17.

In general, the DEIS scoping studies found that the concentration-limited exposure events (scenarios involving food consumption, dust inhalation, and direct gamma radiation exposures) produced the highest calculated doses rather than exposure events involving the consumption of contaminated groundwater (NRC, 1981c, Volume 2, p. 4-5). In addition, the human intrusion analysis was found to provide a useful "hazard index" for ranking or "classifying" the different waste streams for disposal (Op cit.)

7.4 Assumed Definition of Safety

As noted earlier, EPA was responsible for developing and issuing environmental standards, guidelines, and criteria to ensure that the public and the environment were adequately protected from potential radiation impacts. President Richard M. Nixon announced the creation of EPA with the publication of Reorganization Plan No. 3 of 1970. The intent of this plan was to consolidate Federal environmental research, monitoring, standard-setting, and enforcement activities into one agency to ensure environmental protection. This plan also granted EPA its standard-setting authority to establish "generally applicable environmental standards for the protection of the general environment from radioactive material..." (The White House, 1970, 35 FR 15624).

7.4.1 EPA Efforts to Promulgate LLW Standards

In 1972, the EPA Office of Radiation Programs began a program with the CRCPD to examine the practice of shallow-land disposal of commercial LLW (EPA, 1988, p. 1-3). From 1977–78, EPA conducted a series of public workshops to examine the policy and technical issues

[64] Chapter 5, "Long-Term Environmental Protection – Presentation and Analysis of Alternatives," of Volume 2 of NUREG-0782 discusses the analysis of these four scenarios in more detail.

Table 17 **Activity-Limited Exposure Event Scenarios.** Adopted from NRC (1981c, Volume 2 – Chapter 5; and Volume 4 – Appendix G).

The Water Supply is ...	The Exposure Scenario Involves ...
... is an onsite water well located within the disposal site footprint.	... one individual.
... is an onsite water well located at the edge of the disposal site boundary.	... a few individuals.
... is an offsite water well, located 500 m down-gradient from the disposal facility.	... a small population of about 100 individuals.
... is an offsite stream, located 1 km down-gradient from the disposal facility, that receives discharge from a contaminated aquifer that flows below the disposal site footprint.	... a small population of about 300 individuals.

associated with the development of radiation standards (e.g., EPA, 1978a). As a precursor to the required standards, and at about the same time the NRC was developing its LLW disposal standards, EPA proposed Federal guidance for the storage and disposal of all forms of radioactive waste (EPA, 1978c, 43 FR 53262). Meyer (1980, p. 10) described the sources EPA was consulting in the development of its proposed standards at the time. They included the NEPA statutes, the Biological Effects of Ionizing Radiation (BEIR) II recommendations (NAS, 1977), ICRP Publication 26 (ICRP, 1977), and two other reports (National Research Council, 1977; EPA, 1978a). However, the Agency later withdrew its proposed guidance criteria noting that the many types of radioactive wastes and different methods necessary to manage and dispose of them made the issuance of generic disposal guidance too complex and that radiation standards based on waste type would be the best approach (EPA, 1981). Alternatively, EPA decided to promulgate regulations specific to the management and disposal of commercial LLW.

In December 1982, the Commission issued the final 10 CFR Part 61 regulation. Following its release, and depending on its final content, the staff noted its intent to amend 10 CFR Part 61 (and potentially other NRC regulations) once EPA issued its LLW standards if the regulations did not comply with the EPA standards (NRC, 1989c, p. 11). In August 1983, EPA published an ANPR announcing its plans for establishing general environmental radiation protection standards for commercial LLW (48 FR 39563). In connection with the development of these standards, tentatively designated as 40 CFR Part 193, EPA developed the PRESTO-EPA computer code (EPA, 1989a).[65] Similar to the NRC's earlier dose modeling efforts in this regard, the purpose of the EPA-sponsored code was to model radionuclide transport through major environmental pathways to humans. EPA requested that the Agency's Science Advisory Board review a PRESTO-EPA-derived risk assessment prepared as part of the LLW standards development (EPA Science Advisory Board, 1985). As a result of these efforts, EPA transmitted a proposed regulation to OMB in 1987, which was followed by the publication of a two-volume DEIS in June 1988.

[65] PRESTO is an acronym for Protection of Radiation Effects from Shallow Trench Operations. The computer code incorporated a simple one-dimensional ground-water transport model (EPA, 1988, p. 8-2), and although the code could be used to estimate human intruder exposures, EPA expressed the view in its DEIS that the intruder pathway was probabilistic in nature and that safeguards against it should be considered on a site-specific basis. For this reason, EPA did not consider the human intrusion scenario in its DEIS.

In describing the proposed LLW standards, Gruhlke et al. (1989, p. 273) noted that EPA proposed the following definition of LLW:[66]

> "radioactive waste that was not (1) spent fuel, high-level radioactive waste, or transuranic waste, as previously defined in 40 CFR Part 191, (2) or uranium or thorium mill tailings subject to 40 CFR Part 192, or (3) or NARM as defined in 40 CFR Part 764...."

EPA's proposed LLW regulation never cleared the OMB review process. The rule encountered significant interagency opposition during the review because of concerns over the groundwater provisions of the proposed standard (EPA, 2000b, p. 21). Consistent with other regulatory authorities, EPA did successfully promulgate regulations in other nuclear waste management areas - uranium and thorium mill tailings (EPA, 1983b) and HLW (EPA, 1985). EPA also promulgated standards for the maximum concentration limits (MCLs) of radioactive material in its National Primary Drinking Water Standard found at 40 CFR Part 141 (EPA, 1976),[67] as well as standards for airborne emissions of radionuclides under the authority of the Clean Air Act of 1977 (CAA) (Public Law 95-95), as amended.[68]

7.4.2 The NRC Selection of an LLW Standard

EPA's LLW standards and criteria were not available at the time the NRC was developing its LLW regulatory framework. Rather than delay the development of its disposal regulations, the NRC staff decided to postulate a reasonable set of "study guidelines" that could be used as surrogates for the forthcoming EPA standard. At the time, there was no nationally accepted set of safety guidelines defining what level of safety (protection) disposal facilities should provide the public from the health effects of ionizing radiation. Consequently, the staff decided to review the literature[69] and consider the

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[66] Appendix B to this report provides a more detailed discussion of the history and evolution of the LLW definition.

[67] EPA first promulgated interim regulations in 1976 that established MCLs for radium-226 and radium-228 of 5 picocuries per liter (pCi/L). The most recent MCLs can be found in EPA (2000c), which also includes an MCL of 30 micrograms per liter (μg/L) for uranium.

[68] The CAA provided EPA with the specific authority to limit radionuclide emissions to the air. Section 122 of the act directed EPA to review all relevant information and determine whether emissions of radioactive pollutants will cause or contribute to air pollution that may reasonably be anticipated to endanger public health.

In 1979, EPA added radionuclides to the list of hazardous air pollutants under the CAA (EPA, 1979). Among the radionuclides included were those defined by the AEA as source material, special nuclear material, and byproduct materials, as well as TENORM. EPA determined that radionuclides are a known cause of human cancer and genetic damage and that radionuclides cause or contribute to air pollution within the meaning of Section 122(a) of the CAA. Once pollutants are listed, Section 112(b)(1)(B) of the CAA requires EPA to establish National Emission Standards for Hazardous Air Pollutants (NESHAPS) at a level which provides an ample margin of safety. In 1989, EPA published NESHAPs for eight radionuclide source categories, covering an estimated 6300 sources at 40 CFR Part 61 (EPA, 1989c). Eleven parties, primarily representing the regulated community, subsequently sued EPA during the development of the radionuclide NESHAPs.

Between 1992 and 1996, EPA evaluated the ALARA programs at many NRC-licensed facilities. Based on this evaluation, EPA concluded that radionuclide emissions from NRC and Agreement State licensees did not exceed the 10 mrem/yr NESHAP-established standard. The NRC subsequently issued a "constraint rule" under 10 CFR Part 20 that required licensees to maintain emissions below the 10 mrem/yr standard. EPA found that the NRC's regulatory program protects the public health to a safe level with an ample margin of safety and rescinded the NESHAP regulating air emissions from NRC licensees in 1996 (EPA, 1996).

Also see EPA (1989b, 1991).

[69] See Appendix N, "Analysis of Existing Recommendations, Regulations, and Guides," to Volume 4 of NUREG-0782.

recommendations of national and international standard-setting organizations to identify surrogate dose guidelines for the scoping analyses and later the proposed and final rule. See Table 18.

Then, as now, the ICRP was considered to be the authoritative body on the subject of radiation physics. In proposing radiation dose limits, the ICRP observed that radiation risks were a very minor fraction of the total number of environmental hazards to which members of the public were generally exposed. Consequently, in considering what the acceptable magnitude of radiation risk to the public might be, the ICRP suggested that such risks be considered in light of the public acceptance of other (involuntary) health risks encountered in everyday life - generally in the range of 10^{-6} to 10^{-5} per year (Smith, 1995, p. B-2; National Research Council, 1995a, p. 50). In its Publication 26 (ICRP, 1977,p. 23), the ICRP recommended a whole-body dose equivalent of 500 mrem/yr for individual members of a critical group (i.e., tens of individuals) provided that the average annual dose equivalent to individual members of the public (i.e., hundreds of individuals) did not exceed 100 mrem/yr.[70]

In performing the series of hypothetical dose analyses described in NUREG-0456 and NUREG/CR-1005, analysts used the ICRP 1977 recommendations as dose guidelines. See Adam and Rogers, (1978, p. 70) and Rogers (1979, p. 9), respectively. These analyses did not treat separately the estimated exposures to workers and the (hypothetical) inadvertent intruder.

In developing the 10 CFR Part 61 DEIS - NUREG-0782, the staff decided to rely on existing EPA standards in related areas of radiation management and selected a range of public exposure limits from those standards which was expected to bound the forthcoming EPA rule. The staff selected 1 mrem/yr as a lower dose bound since, at the time, it was less than the 4 mrem/yr limit found in the EPA 1976 drinking water standards (EPA, 2000c, 65 FR 76710). See NRC (1981c, Volume 1, p. 34).

Mindful that the NRC's goal was to propose an LLW regulation based on currently available technology, the staff believed that 1 mrem/yr would provide a limit against which the effectiveness of current technology could be analyzed. The staff selected 25 mrem/yr as an upper bound since it was already in use as an existing radiation standard at 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operations" (EPA, 1977b), applied to routine operating releases from nuclear fuel cycle facilities. In proposing this range, the Commission concluded that the forthcoming EPA LLW standards would not be higher than those already set out in 40 CFR Part 190 (NRC, 1981c, Volume 1, p. 34). The Commission applied the specified performance objective in 10 CFR Part 20 to worker safety because it was already using this standard for other NRC-licensed facilities and therefore considered it applicable to an operating commercial LLW disposal facility. Because the human intruder scenario was deemed an unusual (rare) event, likely to involve only one or two individuals, the Commission considered the whole-body dose equivalent of 500 mrem/yr (assuming a 100-year period of institutional controls) acceptable and protective, which was consistent with the earlier recommendations of the ICRP.

From the DEIS scoping analyses, the staff concluded that a limit in the range of existing EPA drinking water regulations (4 mrem/yr) was achievable at the nearest public drinking water supply given some modest increased costs and changes to the reference disposal facility design.

[70]ICRP Publication 26 also introduced a weighted sum dose equivalent to specific organs or tissues that would apply to internal exposures. This weighted sum, which could also be applied to external exposures, became known as an "effective dose equivalent" in ICRP Publication 28 (ICRP, 1978).

Table 18 **Dose Guideline Options Considered by the NRC in Developing 10 CFR Part 61.** Taken from the references cited.

Receptor	NUREG-0456 (Adam and Rogers, 1978)	NUREG/CR-1005 (Rogers, 1979)	NUREG-0782 (NRC, 1981c)	Draft Part 61 (NRC, 1981b)	Final Part 61 (NRC, 1982b)
Public (General Population)	Individual exposures to a few individuals (~10s) – 500 mrem/yr [a]	Individual exposures to a few individuals (~10s) – 500 mrem/yr [a]	25 mrem/yr whole-body exposure to an individual at the disposal site boundary [c]	25 mrem/yr whole-body, 75 mrem/yr thyroid, and 25 mrem/yr to any other organ exposures to an individual at the disposal site boundary	25 mrem/yr whole-body, 75 mrem/yr thyroid, and 25 mrem/yr to any other organ exposures to an individual at the disposal site boundary
	Individual exposures to many individuals (~100s) – 100 mrem/yr [a]	Individual exposures to many individuals (~100s) – 100 mrem/yr [a]		Meet EPA requirements of 40 CFR Part 141 for the nearest drinking water supply [e]	
Worker			10 CFR Part 20 [b]	10 CFR Part 20 [b]	10 CFR Part 20 [b]
Intruder			500 mrem/yr [d]	500 mrem/yr [d]	Not specified but implied [f]

a. NUREG-0456 dose guidelines based on recommendations of the ICRP (1977).
b. Includes consideration of ALARA principles.
c. Based on view that releases would not be higher than standards already established for fuel cycle facilities found at 40 CFR Part 190 (EPA, 1977b). Commission considered a range of 1 mrem/yr to 25 mrem/yr.
d. Considered to be an unusual event. Dose guidelines in NUREG-0782 and Draft 10 CFR Part 61 based on recommendations of the ICRP (1977).
e. Specifically, maximum radiation concentration limits of 10pCi/L above background levels (or 4mrem/yr whole-body exposure). See EPA's National Primary Drinking Water Standards (EPA, 1976).
f. Tied to Table 1 concentration limits in draft 10 CFR Part 61 regulation but 500 mrem/yr retained as one of the bases for limits specified in the tables in the final regulation.
g. Note that the technical bases for dose limits under 10 CFR 61.41, the basis for the concentration limits in the intruder scenario, and the current 10 CFR Part 20 are different. For short-lived radionuclides, the difference is negligible; for long-lived radionuclides, the difference may be significant.

The staff also concluded that meeting the EPA drinking water standards at the nearest public drinking water supply would result in annual potential exposures of less than 25 mrem whole body, 75 mrem thyroid, and 25 mrem to any other organ of an individual who might consume water from a well located at the site boundary. Therefore, the staff selected an annual exposure limit of 25 mrem whole body, 75 mrem 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, as the preferred performance objective when the proposed regulation was published for public comment (46 FR 38063).

Following a review of the public comments on its proposed regulation, the NRC made two changes to the Subpart C performance objectives in the final rule. The first change was in response to a comment from EPA, which expressed the view that it was inappropriate to apply the agency's drinking water standard in the manner proposed in draft 10 CFR 61.41 (47 FR 57448). The Commission deleted that provision from its final rule. The second comment concerned the proposed 500-mrem limit for whole-body dose to the human intruder. Many commenters suggested that the intruder performance objective was too restrictive. They also argued that a licensee would not be able to monitor or demonstrate compliance with a specific dose limit for an event that might occur several hundred years in the future (47 FR 57449). The Commission deleted this provision from the Subpart C performance objectives but retained 500-mrem limit as a basis for the waste classification limits.

7.4.3 The NRC Proposed LLW Classification System

As a means of relating waste characteristics to the Subpart C performance objectives, the NRC devised and incorporated a simple waste classification scheme into the proposed regulation. It based this three-tier classification system on the earlier thesis demonstrated during the rulemaking scoping process that waste characteristics provide some level of assurance that the performance objectives will be met. Key decision parameters in the waste classification system were the physical stability of the waste form[71] and its isotopic concentration. The NRC viewed these parameters as important for they provide the minimum information necessary for basic decisions on the safe handling and disposal of commercial LLW.

The three classes of LLW defined in 10 CFR 61.55 as acceptable for disposal in near-surface facilities were designated Class A, B, and C, with the highest being Class C. Certain minimum requirements and stability requirements[72] and

[71]In the Statements of Consideration for the final rule (NRC, 1982b), the Commission noted that "waste that is stable for a long period helps to ensure the long-term stability of the site, eliminating the need for active maintenance after the site is closed. This stability requirement helps to assure against water infiltration caused by failure of the disposal covers and, with the improved leaching properties implicit in a stable waste form, minimizes the potential for radionuclide migration in groundwater. Stability also plays an important role in protecting an inadvertent intruder, since the stable waste form is recognizable for a long period of time and minimizes any effects from dispersion of the waste upon intrusion...." The Commission also noted its belief that "to the extent practicable, waste forms or containers should be designed to maintain gross physical properties and identity over 300 years, approximately the time required for Class-B waste to decay to innocuous levels..." (47 FR 57457).

[72]The minimum requirements that all waste forms must meet to be acceptable for near-surface disposal appear in 10 CFR 61.56(a). In addition to these minimum requirements, certain wastes (i.e., Class B and C wastes, and Class A waste that is to be co-disposed with Class B and C waste) must be physically stabilized and meet the requirements of 10 CFR 61.56(b). Stability is defined in terms of the ability to keep the dimensions and form of the waste material under anticipated disposal conditions. Stability can be achieved by relying on the inherent physical properties of the waste form itself (e.g., activated metals), by rendering the waste into a more stable form (through cement solidification), by placing the waste in a high-integrity container (HIC), or relying on the structural

specifications for maximum allowable concentrations of certain radionuclides in each class determine the class designations. By controlling isotope concentrations in each waste class (and to a lesser degree, the site inventory), the regulation seeks to control radiation exposures to inadvertent intruders (47 FR 57455). Class A waste includes primarily lightly contaminated paper, cloth, and plastics. These wastes must be segregated from other LLW during disposal because of their potential for compaction over time owing to decomposition and the subsequent potential for subsidence of the ground surface above disposal cells. The isotope concentrations in this class of wastes are not to exceed the values listed in the regulation. Class B waste by definition meets more rigorous physical stability requirements than Class A waste. This waste class is also permitted higher isotope concentrations. The physical form and characteristics of Class B waste must also meet the minimum and stability requirements of the regulation. Class C waste is generally considered intruder waste (46 FR 38085). Although this higher activity, longer lived LLW is generally suitable for SLB, it requires special measures to protect against human intrusion after institutional controls lapse. The regulation requires that any Class C waste, which could have concentrations that would cause exposures greater than 500 mrem/yr, be protected from human intrusion by deeper burial and/or through the use of some type of engineered intruder barrier. [73] Wastes exceeding the Class C concentration limits are, by regulation at 10 CFR 61.55(a)(2)(iv), "generally not acceptable" for SLB.

As noted earlier in this report, the 10 CFR Part 61 regulation is deliberately structured around the three-tier LLW classification system defined by the concentration of radionuclides in the waste form, as well as the physical characteristics of the waste form. This classification system is integrated with the stylized human intrusion scenarios that form the basis for the Subpart C performance objectives. Despite this rigor, the Commission decided to allow for the consideration of alternative LLW classification schemes at 10 CFR 61.58, "Alternative Requirements for Waste Classification and Characteristics," on a specific (case-by-case) basis so long as compliance with the Subpart C performance objectives can be demonstrated. In 10 CFR 61.58, the Commission acknowledges the need to allow for the future disposal of different waste types, physical forms, and quantities that were not necessarily foreseen at the time the regulation was being developed.

Following promulgation of the commercial LLW disposal regulation, the NRC staff began to work with Agreement States on the development of comparable regulations. See Ratliff et al. (1985).

7.4.4 Summary of the Final 10 CFR Part 61

The Commission developed the final LLW disposal regulation at 10 CFR Part 61 with the intent of addressing some of the past LLW site performance concerns and developing guidelines for establishing technical criteria for selecting, evaluating, licensing, and operating new commercial disposal sites. The final regulation covers all phases of shallow, near-surface LLW disposal from site selection through facility design, licensing, operations, closure, postclosure stabilization, to the period when active institutional controls end. See Figure 1.

Key provisions of the Commission's commercial LLW disposal regulation include the following:

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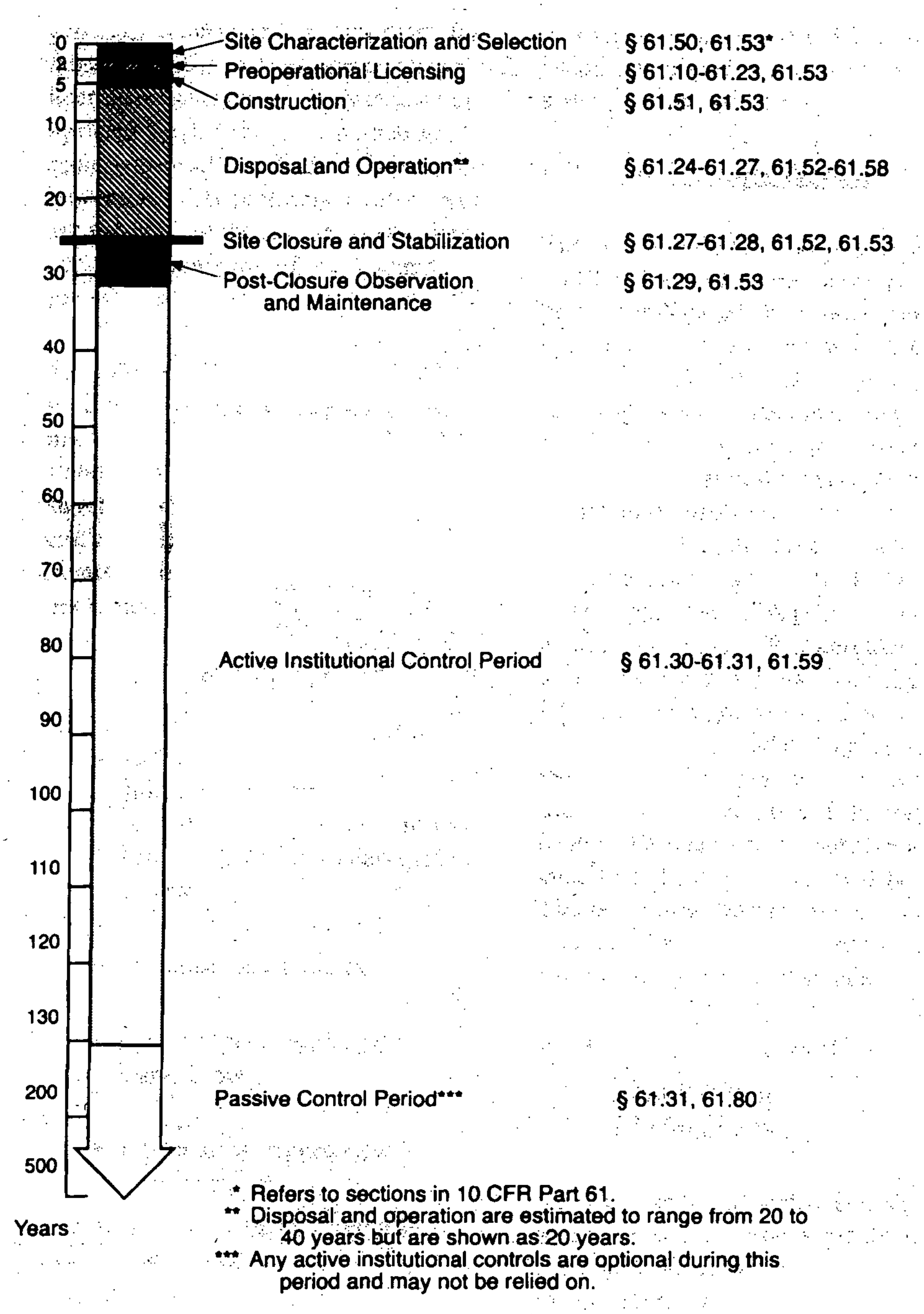
stability of the disposal unit itself (e.g., vault disposal).

[73] The calculation performed to establish the Class C limits was based on a postulated SLB disposal method. The Commission considers these limits conservative, since there may be near-surface disposal methods (and costs) other than SLB (NRC, 1987a, 52 FR 5999).

Figure 1 **Lifecycle of a Hypothetical Commercial LLW Radioactive Waste Disposal Facility.** Taken from NRC (1989, p. 2c).



- specifying minimum geologic/ geomorphic characteristics of an acceptable LLW disposal site using the site suitability requirements at 10 CFR 61.50,"Disposal Site Suitability Requirements for Land Disposal"

- defining a three-tier waste classification system for commercial LLW disposal based on the concentrations of longer lived radionuclides at 10 CFR 61.55, "Waste Classification"

- specifying the minimum requirements that all commercial LLW forms must meet to be acceptable for near-surface disposal at 10 CFR 61.56(a), "Waste Characteristics"[74]

- introducing requirements for caretaker oversight of LLW disposal sites for a period of 100 years following facility closure at 10 CFR 61.59,"Institutional Requirements"

The regulation also establishes procedures, criteria, terms, and conditions under which the Commission would issue and renew licenses for the SLB of commercially generated LLW.

In issuing its final LLW regulation, the NRC staff prepared a FEIS in response to public comments received on the DEIS (NUREG-0782) and the earlier proposed rule. The FEIS, designated NUREG-0945, was not an updated version of the DEIS. Rather, it referenced that earlier document and presented the staff's decision bases and conclusions (costs and impacts) for the Commission's final regulation. Consistent with NEPA, the staff also prepared a comparative evaluation of alternatives to highlight the costs and impacts of the 10 CFR Part 61 regulation. These alternatives included a review of past LLW disposal practices, existing LLW disposal practices, disposal practices based on proposed final 10 CFR Part 61 regulatory requirements (the preferred alternative), and an upper-bound example. Lastly, the earlier impacts analysis methodology (Oztunali et al., 1981) used to estimate radiological doses was updated.

Although the Commission left many of the proposed 10 CFR Part 61 regulations substantially unchanged following the public comment period, some rule changes were made in response to those comments. The specific rule changes in response to public comments were described in the Commission's 1982 *Federal Register* notice (47 FR 57446). Volume 2, Appendix B ("Staff Analysis of Public Comments on Proposed 10 CFR Part 61 Rulemaking") of the FEIS report also provides a detailed accounting of the staff's views concerning individual stakeholder comments.

In addition, the FEIS clarified several specific rule provisions, including the following:

- Doses were generally presented only for the whole body, thyroid, and bone.

- Waste classification represented a combination of waste form, radionuclide characteristics, radionuclide concentration, method of emplacement, and to some extent, site characteristics.

- The concentration limits for Class A and C waste disposal were reevaluated.[75]

- The Class C waste concentration limits were raised by a factor of 10 (to 100 nCi/g) for all radionuclides, except for

[74] In addition to these minimum requirements, certain LLW classes must be physically stabilized and meet the requirements at 10 CFR 61.56(b).

[75] The Commission established the concentration limits based on the staff's understanding at the time of the characteristics and volumes of LLW reasonably expected to the year 2000, as well as potential disposal methods (52 FR 5999).

cesium-137.[76]

- A fourth class of LLW (GTCC LLW) was considered generally unacceptable for near-surface, shallow-depth disposal.[77]

In 1992, the staff proposed to amend 10 CFR Part 61 to clarify that the regulations would also apply to the licensing of an above-ground disposal facility (i.e., an above-ground vault - AGV). See NRC (1992b). The staff amended the definition of "land disposal facility" (at 10 CFR 61.2, "Definitions") to clarify that LLW disposal facilities also include those that are on or protrude through the ground surface and do not have an earthen cover (57 FR 8094). However, in adopting the amendments (definition), the Commission chose not to develop specific above-ground technical criteria until actual plans to develop such a facility existed. See NRC (1993a, 58 FR 33888).

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[76]Based primarily on two considerations: (a) the reduced likelihood of significant human intruder exposures because of the regulatory requirement for the adoption of passive warning devices at a LLW disposal facility, at 10 CFR 61.31(c)(2) ("Termination of License"); and (b) the expected difficulty (and remote likelihood) of coming into contact with relatively small volumes of Class C LLW, at depth. See NRC (1982a, Volume 1, p. 5-33; and Volume 2, pp. B-83 - B-89).

[77]In 1986, the NRC staff updated impacts analysis methodology (Oztunali et al., 1981) to allow for improved consideration of the costs and impacts of treating and disposing of LLW that was close to or exceeding the Class C concentration limits. See Oztunali and Roles (1986) and Oztunali et al. (1986). The updates included the use of the more recent health physics guidance found in the ICRP Publication 30 series.

8 THE MANAGEMENT OF GTCC LLW

As defined in 10 CFR 61.55(a)(4)(iv) ("Waste Classification"), quantities of LLW with radionuclide concentrations in excess of certain values are referred to as GTCC. Small volumes of GTCC LLW result primarily from the operation of commercial nuclear power reactors and other fuel cycle facilities. Examples include activated metal hardware (e.g., nuclear power reactor control rods), some spent fuel disassembly hardware (Stellite balls), some ion exchange resins, filters, evaporator residues, some sealed sources that are used in medical and industrial applications, and moisture and density gauges. The radionuclides that frequently contribute to wastes being classified as GTCC LLW include those found in 10 CFR 61.55, Table 2. By law, DOE is responsible for disposing of GTCC LLW.

8.1 NRC Activities

In a 1987 ANPR (52 FR 5992), the Commission proposed to redefine the existing definition of HLW in a manner that would apply the term "high-level radioactive waste" to materials in amounts and concentrations exceeding numerical values that would be stated explicitly in a table. The Commission proposed to classify wastes as HLW or non-HLW. Wastes that could not be disposed of safely in a hypothetical "intermediate" disposal facility would be classified as HLW (52 FR 5996). The technical basis supporting this proposal was described in Kocher and Croff (1987).

Following a review of public comments on the ANPR, the Commission adopted an alternative strategy. In 1988 (53 FR 17709), the NRC published its proposed amendments to 10 CFR Part 61 recommending, in the first instance, GTCC LLW disposal in a separate facility licensed under 10 CFR Part 60, which are the NRC's generic regulations for the disposal of SNF and other HLW (NRC, 1988c). The Commission's opinion was that, given the quantities of waste of concern[78] and the likely costs of disposal, a separate disposal facility unique to GTCC LLW was not justified. That same year, OTA (1988) published an independent report with recommendations on the issue that generally supported the Commission's 1988 proposed rulemaking position. In summary, both OTA and the Commission took the position that if a review determined that the impact of GTCC LLW disposal on any HLW repository was unacceptable, then DOE should develop an alternative disposal concept. The Commission proposed amendments to 10 CFR Part 61 that would require the deep geologic disposal of GTCC LLW in a HLW repository unless the Commission approved an alternative means of disposal elsewhere. The intent of this action was to obviate the need for amending the existing classifications of LLW and HLW, thereby insuring that GTCC waste would be disposed of in a manner consistent with the protection of public health and safety. Following a review of public comments in 1989, the Commission amended 10 CFR 61.55(b)(2)(iv) to permit the disposal of GTCC LLW in an HLW geologic repository licensed under 10 CFR Part 60 or some other type of disposal facility design approved by the Commission (NRC, 1989a, 54 FR 22578).

On November 2, 1995, the Commission received a petition from the Portland General Electric Company (the utility licensed by the NRC to operate the Trojan Nuclear Power Plant) requesting that the NRC's regulations at 10 CFR Part 72 (then titled "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste") be amended to specifically provide for storage of GTCC LLW

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[78]Expected to be in the range of 70,000 to 170,000 ft^3 (2000 to 4800 m^3) through 2030, citing DOE estimates (54 FR 22580). This volume corresponds approximately to a single emplacement drift in an HLW repository.

at an independent spent fuel storage installation (ISFSI) or a monitored retrievable storage (MRS) facility pending its transfer to a permanent disposal facility. See NRC (1996a). Because interim storage of the GTCC LLW would be accomplished in a manner similar to that used to store SNF at an ISFSI, the petitioner believed public health and safety and environmental protection would be ensured. The NRC staff evaluated the petition and the six comments received during a public comment process,[79] which all supported the petition, and concluded that the petitioner's concept had merit because there are currently no routine disposal options for GTCC LLW. The Commission subsequently amended 10 CFR Part 72 to allow licensing for the interim storage of GTCC waste in a manner consistent with current licensing for the interim storage of SNF. See NRC (2001b). The amendments applied only to GTCC LLW generated at commercial nuclear power plants.

8.2 DOE Activities

The 1988 OTA assessment (p. 31) expressed the opinion that it would be 15 to 20 years before generators would have disposal access for GTCC LLW. As an interim measure, OTA recommended extended onsite waste storage for those generators with the capacity to do so. For those without this capacity, OTA recommended storage at an NRC-licensed DOE disposal facility (Op cit.). In 1989, an examination of the potential need for Federal interim storage of nuclear waste did not refer to the management of GTCC LLW. See Monitored Retrievable Storage Review Commission (1989).

Section (3)(b)(1)(D) of the LLWPAA directed the Secretary of Energy to issue a report recommending safe disposal options for GTCC LLW. In 1987, the Secretary issued such a report (DOE, 1987), which also described the types and quantities of GTCC LLW being generated at the time. Hulse (1991) and Lockheed Idaho Technologies Company (1994a, 1994b[80]) have updated earlier estimates of current and future volumes of GTCC LLW from the original 1987 census.

DOE published a notice of inquiry (NOI) in 1995 soliciting public and stakeholder input to the development of a strategy for the management and disposal of GTCC LLW. In its *Federal Register* notice (DOE, 1995), the Department proposed to prepare a preliminary EIS that indicated its intent to begin the scoping process for developing GTCC LLW disposal options. The scoping process included three public meetings with stakeholders. The 1995 NOI proposed five management options to consider when defining any disposal strategy. The Department noted that it would address the decisionmaking process for selecting the preferred management option in supplemental NEPA documentation (60 FR 13425). Following the conduct of three public meetings, the Department took no additional action to develop the preliminary EIS.

[79]The NRC published a notice of receipt of the petition in the *Federal Register* on February 1, 1996 (NRC, 1996a, 61 FR 3619), allowing a 75-day comment period. The NRC staff evaluated the petition and the comments and concluded that the petitioner's concept had merit. The requirements at 10 CFR Part 72 provide only for licensing storage of spent fuel at an ISFSI and storage of SNF and solid HLW at an MRS. Nonetheless, a reactor licensee could elect to store GTCC LLW at an ISFSI site under licenses issued under other NRC regulations, namely, 10 CFR Part 30 and 10 CFR Part 70. However, the 10 CFR Part 30 and 10 CFR Part 70 regulations at the time did not provide specific licensing criteria for storage of GTCC LLW at an ISFSI, and thus the petitioner or the commenters may not have known that GTCC waste can be stored under a 10 CFR Part 30 or a 10 CFR Part 70 license.

[80]This study concerned sealed sources, which were estimated to number about 250,000 in the United States.

Alternatively, in 2005, the Department published an advance NOI to prepare an EIS for GTCC LLW. See DOE (2005).[81] As part of the EIS development process, DOE proposed that the NRC staff participate as a cooperating agency (NRC, 2005a). After review, the Commission rejected this proposal and, in a 2005 SRM, directed the NRC staff to comment on DOE's GTCC LLW EIS (NRC, 2005b).

[81]It should be noted that in a review of potential waste streams for an HLW repository, another DOE program office has reviewed the characteristics of GTCC LLW. See ORNL (1992). In the FEIS for the Yucca Mountain geologic repository, DOE accounted for GTCC LLW disposal in a bounding analysis that estimated the environmental impacts of repository disposal activities (DOE, 2002, pp. A-57–A-61). However, there are no published plans at this time suggesting that DOE will place GTCC LLW in the proposed HLW repository.

9 OTHER NRC LLW PROGRAM DEVELOPMENTS

Section 6 of this report describes the regulatory products the staff prepared to help potential licensees develop complete and high-quality license applications based on 10 CFR Part 61 requirements. Some of these products also instruct the staff in how to review those license applications.

In addition to the development of guidance, the NRC staff has undertaken a number of initiatives intended to aid in the implementation of the NRC's LLW regulatory framework. Section 9.1 of this report describes these initiatives, which occurred at various times over the years in relation to the development of the 10 CFR Part 61 regulatory and guidance framework previously described. The Office of Nuclear Regulatory Research (RES) also undertook independent LLW technical work, summarized in Section 9.2. As part of an agency-wide planning initiative in the early 1990s, the NRC staff undertook a broad reassessment of its LLW program. Section 9.3 of this report describes this reassessment.

9.1 LLW Regulatory Guidance and Policy

The NRC staff has historically relied on the use of guidance documents such as technical positions or branch technical positions (BTPs) as a means of interpreting the Commission's regulatory requirements. In addition, the Commission periodically issues policy statements to communicate its views on some particular issue to licensees and stakeholders. The Commission does not intend these communications as substitutes for the regulations and does not require compliance with them. They generally represent the staff's recommendations on preferred approaches to address the requirements[82] or the Commission's views on issues bearing on its regulatory activities. Table 19 summarizes the subject areas for which the Commission has issued policy statements or the staff has provided additional regulatory guidance to potential LLW licensees.

The NRC also sponsored many technical assistance projects intended to provide the predictive models and analytical tools necessary to evaluate the performance of LLW disposal facility systems and components. Areas of past interest included waste package container performance, evaluation of leaching phenomena, hydrogeological and hydrochemical characterization and modeling, and cover performance. Most of this work focused on SLB disposal facilities. The use of predictive models to evaluate the performance of a disposal system or its components is generally referred to as "performance assessment" and has gained increased use in the NRC's waste management programs over the years. See Eisenberg et al. (1999). As early as 1987, the staff recognized that it would need to acquire or develop some type of assessment methodology for estimating the performance of 10 CFR Part 61 LLW disposal facilities (52 FR 5996). To provide focus and integration of the overall program, the staff developed an LLW performance assessment strategy (Starmer et al., 1988). Sandia National Laboratories subsequently developed a proposed LLW performance assessment methodology (PAM) based on this strategy.

In terms of measuring the effectiveness of disposal facility designs against the 10 CFR Part 61 performance objectives, the guidance provided by NUREG-1199, NUREG-1200, and

[82]In general, the staff believes that methods and solutions differing from those set out in guidance documents should be acceptable if they provide a sufficient basis for the findings requisite to the issuance of a permit or license by the Commission.

Table 19 Additional NRC Technical Guidance and Policy Direction in the Area of LLW

Title	Scope	Reference
Commission Policy / Position Statements		
"Policy Statement on Low-Level Waste Volume Reduction"[a]	Licensees are encouraged to establish programs to result in good volume reduction practices in order to (a) extend the operational life of existing commercial LLW disposal sites; (b) alleviate concerns regarding existing LLW disposal capacity should there be delays in establishing regional disposal facilities; and (c) reduce the number of LLW shipments.	NRC (1981d)
"Regulatory Issues in Low-Level Radioactive Waste Performance Assessment" (SECY-96-103)[b]	The Commission expressed its views on (a) consideration of future site conditions, processes, and events; (b) performance of engineered barriers; (c) specification of a timeframe for an LLW performance assessment; (d) treatment of sensitivity and uncertainty in LLW performance assessments; and (e) the role of performance assessment during the operational and closure periods.	NRC (1996c)
Technical Positions / Recommendations		
Branch Technical Position on "LLW Burial Ground Site Closure and Stabilization" (NUREG-0782)	In closing and stabilizing an LLW disposal facility, 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 to the point when the NRC license is terminated.	NRC (1979a)
Branch Technical Position on "Site Suitability, Selection, and Characterization" (NUREG-0902)	Provides the staff's interpretation of (a) the site suitability requirements proposed at 10 CFR 61.55; (b) the site selection process as related to the consideration of alternatives, as required by the NEPA process; and (c) the scope of site characterization activities necessary to develop site-specific data necessary for a 10 CFR Part 61 license application and environmental report.	Siefken et al. (1982)
Technical Position on "Radioactive Waste Classification"	Provides guidance on procedures to determine the presence and concentrations of radionuclides listed in 10 CFR 61.55, and thereby classifying the waste for near-surface disposal.	NRC (1983a)
Technical Position on "Waste Form"	Provides guidance on acceptable methods for demonstrating compliance with the waste form structural stability requirements found at 10 CFR 61.56.	NRC (1991b)
Branch Technical Position on "Concentration Averaging and Encapsulation"	Defines a subset of concentration averaging and encapsulation practices that the staff would find acceptable in determining the concentrations of 10 CFR 61.55 tabulated radionuclides.	NRC (1995a)
"A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities —Recommendations of NRC's Performance Assessment Working Group" (NUREG-1573)[c]	Describes (a) an acceptable approach for systematically integrating site characterization, facility design, and performance modeling into a single performance assessment process; (b) five principal regulatory issues related to the interpretation and implementation of the 10 CFR Part 61 performance objectives and technical requirements, all of which are integral to an LLW performance assessment; and (c) how to implement the NRC's PAM.	NRC (2000)

a. The policy statement acknowledged but did not specifically identify LLW volume reduction technologies under review at the time. See Trigilio (1981). In a report prepared for the ACNW, Long (1990) examined the use of incineration as a potential volume reduction method.
b. The Commission later restated its positions in NUREG-1573.
c. See Appendix D to this report.

NUREG-1300 was general and did not address many specific implementation issues and acceptable approaches for resolving them. Moreover, the existing guidance documents did not explicitly deal with the relationships between the overall 10 CFR Part 61 data and design requirements and the specific LLW performance assessment needs. Previously, site characterization, facility design, and performance modeling were considered separate activities. To clarify these and other issues for potential applicants, the staff developed detailed information and recommendations related to the performance objective concerned with the radiological protection of the general public (at 10 CFR 61.41) in NUREG-1573, "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities - Recommendations of NRC's Performance Assessment Working Group," (NRC, 2000).

9.2 LLW Research

Once the NRC had established its regulatory framework, the staff focused its attention on conducting technical studies and analyses intended to improve the understanding of the behavior of a disposal facility and its components based on lessons-learned at commercial and DOE-operated LLW disposal sites. Many of the NRC regulatory products and activities described elsewhere in this report were conducted by or on the behalf of NMSS. In addition, RES has sponsored a substantial amount of LLW technical work. For example, in 1989, RES staff published an research program plan which presented its strategy for pursuing LLW research studies. See O'Donnell and Lambert (1989). NUREG-1573 cites many of the RES-sponsored research projects completed through 2000 in the area of LLW based on that strategy. Appendix E to this report contains a selected bibliography of technical reports and papers sponsored by RES in the LLW area since NUREG-1573 was published.

As noted earlier in Section 2.3 of this report, the USGS had certain basic and applied research responsibilities in the area of LLW. In April 1992, the USGS cooperated with RES on basic research applied to LLW siting, monitoring, and modeling issues through an interagency memorandum of understanding (MOU). A major accomplishment of the MOU was the convening of the joint workshop on research related to LLW disposal, held from May 4–6, 1993, at the USGS National Center in Reston, Virginia. The workshop covered (a) surface and ground-water pathway analysis, (b) ground-water chemistry, (c) infiltration and drainage, (d) vapor-phase transport and volatile radionuclides, and (e) ground-water flow and transport field studies. The workshop and its subsequent proceedings (Stevens and Nicholson, 1996) addressed the current state of the art and practice in research related to LLW disposal hydrogeologic, hydrologic, geochemical, and performance assessment issues at commercial and military-related facilities. Presenters and participants came from academia, DOE national laboratories, consulting companies, Federal and state agencies, and international research centers.

Other related workshops on modeling or monitoring and their published proceedings include (a) NUREG/CP-0163, "Proceedings of the Workshop on Review of Dose Modeling Methods for Demonstration of Compliance with the Radiological Criteria for License Termination" (Nicholson and Parrott, 1998), (b) NUREG/CP-0177, "Proceedings of the Environmental Software Systems Compatibility and Linkage Workshop" (Whelan and Nicholson, 2002), which helped to initiate the MOU on multimedia environmental modeling signed by nine Federal agencies[83], and (c) NUREG/CP-0187, "Proceedings of the International Workshop on Uncertainty, Sensitivity, and Parameter Estimation for Multimedia Environmental Modeling" (Nicholson et al.,

[83]See *http://www.ISCMEM.org*.

2004). These workshop proceedings highlight the advances in environmental modeling and performance assessments applicable to LLW issues since the 1993 USGS-NRC LLW workshop.

RES has issued numerous technical reports and sponsored many technology transfer workshops. Of particular significance to LLW are NUREG/CR-6805, "A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites" (Neuman and Wierenga, 2003), and NUREG/CR-6843, "Combined Estimation of Hydrogeologic Conceptual Model and Parameter Uncertainty" (Meyer et al., 2004), which discuss guidance and tools for modeling hydrogeologic systems and radionuclide transport relevant to LLW.

9.3 Strategic Planning

In addition to the guidance development activities described above, in the early 1990s, the staff undertook a broad reassessment of its LLW program which considered factors outside the control of the NRC. This assessment took place at the same time that other reviews of the national program were occurring (e.g., GAO, 1992a).

As part of the NRC's first assessment, the staff categorized strategies and options for the Commission to consider to advance the goals and objectives of the LLWPAA. These included expanding technical assistance, revising the existing 10 CFR Part 61 regulatory framework, seeking greater public involvement in the current LLW program, and passing additional Federal LLW legislation. See Taylor (1993). Focusing on the option to revise 10 CFR Part 61, the staff identified specific areas in the existing regulation as potential candidates for revision with the goal of enhancing public health and safety through the establishment of more precise regulations coupled with addressing the states' experiences in applying the rule. Table 20 lists the candidate areas identified in the current regulation as proposed for revision. These areas include so-called "active" disposal concepts.[84]

At the time these candidate areas were proposed, the staff's position was that there was no evidence that the current regulatory framework was impeding the development of new LLW disposal facilities (Taylor, 1993, p. 6). In fact, the staff and several of the Agreement States believed that major revisions to 10 CFR Part 61, along with the requirement for conforming revisions by the Agreement States, could create instability in current LLW siting and licensing efforts (Op cit., pp. 6–7).

As an alternative to revising specific sections of the regulation, the staff proposed to revise 10 CFR Part 61 by making it less specific and more performance-oriented with a greater emphasis on the overall performance objectives. The staff introduced this proposal before the Commission published its Probabilistic Risk Assessment (PRA) Policy Statement. See Appendix F to this report. Under such an approach, the staff would develop guidance documents to address siting, design, construction, operation, closure, and waste form issues.[85] There is no information to suggest that the Commission responded to the staff's 1993 analysis. That analysis was first overtaken in 1995 by the issuance of a Commission paper SECY-95-201, entitled "Alternatives to Terminating the NRC's Low-Level Radioactive Waste Disposal Program" (NRC, 1995c), which described three options for the future of the

[84]The staff generally defined active disposal concepts to include retrievablility, active maintenance and monitoring, and a longer period of custodial oversight (Taylor, 1993, p. 7).

[85]At the time, the staff estimated that it would take 2 to 3 years to complete a performance-based rulemaking and an additional 3 years for the Agreement States to adopt it.

Table 20 **Potential Candidate Areas in 10 CFR Part 61 Identified for Amendment by the NRC Staff in 1993.** Adopted from Attachment B to NRC (1993a).

10 CFR Part 61			1993 NRC Staff Recommendation
Requirement	**Subpart**	**Subject Area**	
10 CFR 61.29	B	Active Maintenance	In conjunction with a longer time period of institutional control, include provisions in the regulation for more inspections and preventive maintenance of the disposal facility following closure to assure that the facility is performing as intended.
10 CFR 61.41	C	Performance Objectives	Establish dose requirements more stringent than the current 25 mrem/yr for protection of the general population .
10 CFR 61.50	D	Technical Requirements for Land Disposal Facilities	Develop specific technical criteria to cover disposal in above-ground vaults, which are not currently addressed in the regulations.
10 CFR 61.50(a)	D	Site Suitability Requirements	Current requirements are considered to be "minimum" basic requirements. Past experience indicates the need for more specific siting and design requirements. More credit is also needed for performance of engineered barriers to compensate for site deficiencies.
10 CFR 61.53	D	Environmental Monitoring	In conjunction with a longer time period of institutional control, include provisions in the regulation for a period of environmental monitoring after the 100-year caretaker period.
10 CFR 61.59(a)	D	Land Ownership	Consider assigning a responsible third party to the caretaker role other than the government.
10 CFR 61.59(b)	D	Institutional Control Period	Extend governmental caretaker period for more than 100 years.
10 CFR 61.55 and 10 CFR 61.56	D	Waste Classification and Characterization	Include specific concentration-averaging requirements in the regulations.
n/a	n/a	Retrievability Option	Currently, there is no provision in the regulation to require that the wastes be recoverable should the disposal facility fail to perform as intended.
n/a	n/a	Groundwater Protection Requirements	The regulation could be made more explicit on how the ground-water resource would be protected. ACNW has previously recommended specific regulatory action in this area.

NRC's LLW program.[86] In SECY-95-201, the staff recommended reducing the current NRC program by eliminating or reducing various parts of the program based on current developments in the national program and the reduced budget allocations at the agency. The ACNW provided its views on these recommendations in a letter dated December 29, 1995. (Also see Section 10.2.1 of this report.)

Later, in 1995, the Commission's Strategic Assessment and Rebaselining Initiative superseded SECY-95-201. This initiative was a four-phase strategic planning exercise, the goal of which was to assess and rebaseline the NRC's regulatory activities to provide a sound foundation for future agency direction and

[86]Briefly described, these options are (a) continue the program as currently in place; (b) reduce the program by eliminating or reducing various parts; and (c) terminate all parts of the LLW program.

decisionmaking. The principal focus of the initiative was the identification of key strategic issues associated with the NRC's primary responsibility to protect public health and safety and the environment. These key issues were called direction-setting issues (DSIs). For each of the 16 DSIs, the staff developed background papers containing the Commission's preliminary views on policy options in the DSI topical areas. The goal in developing these papers was to identify and classify issues that affected each of the NRC programs and, ultimately, the means by which the Agency does its work. The Strategic Planning Framework (NRC, 1996d), a compilation of these 16 DSIs, became available for public comment on September 13, 1996.

DSI 5 applied to the NRC's LLW program. The position paper superseded the staff's earlier 1993 program analysis by recommending six options for managing the NRC's LLW programs. The six (unranked) options proposed were:

(1) The NRC assumes a greater leadership role in the national LLW program.

(2) The NRC assumes a stronger regulatory role in the national LLW program.

(3) The NRC retains its current LLW program.

(4) The NRC recognizes progress in the national LLW program and reduces the size of its current program.

(5) The NRC recommends to Congress that its LLW responsibilities be transferred to EPA.

(6) The NRC encourages the long-term storage of LLW under the concept of "assured storage."

In an SRM dated March 7, 1997, the NRC Executive Director of Operations informed the staff of the Commission's preference for Option 3, to maintain the current LLW program. The ACNW provided its views regarding DSI 5 and other cross-cutting issues outlined in the Strategic Planning Framework in a letter dated January 30, 1997.

PART III. PAST NRC ADVISORY COMMITTEE REVIEWS

10 THE ACRS AND THE ACNW

The NRC (and its predecessors) has relied on independent advisory committees to review its regulatory activities. Before 1988, the ACRS Waste Management Subcommittee reviewed the NRC's LLW activities. In April 1988, the Commission established the ACNW as a separate advisory committee to continue this oversight. Collectively, both Committees have commented on various LLW management issues as well as the implementation of the NRC's LLW regulatory framework in more than 40 letter reports. This section summarizes the past advice of the ACRS and the ACNW in the commercial LLW area.

10.1 Background

The NRC established the ACNW as a Federal advisory committee to provide independent technical advice on agency activities, programs, and key technical issues associated with the regulation, management, and safe disposal of certain types of radioactive waste. The Committee is independent of NRC staff and reports directly to the Commission, which appoints its members. Consistent with the NRC's regulatory mission, the ACNW undertakes independent studies and reviews of the transportation, storage, and disposal of HLW and LLW, including the interim storage of SNF, materials safety, and facility decommissioning. The ACNW also independently evaluates staff efforts to develop and apply a risk-informed and performance-based regulatory framework to these programs, consistent with Commission direction. This includes reviews of and comments on proposed rules, regulatory guidance, licensing documents, staff positions, and other issues, as requested by the Commission.

The provisions of the Federal Advisory Committee Act of 1972 (FACA) (Public Law 92-463) govern the operational practices of the ACRS and the ACNW. FACA requires that, with very few exceptions, advisory committee meetings will be open the public (General Services Administration, 2001).[87] Letter reports document the results of the Committees' reviews, consisting of both comments and recommendations. Each year, the Commission publishes the compiled letter reports of the ACRS and the ACNW as updates to NUREG-1125 (ACNW, 1985-89) and NUREG-1423 (ACNW, 1990-2006), respectively.

The ACNW can trace its history to the ACRS, a statutory Federal advisory committee created in the late 1940s. The ACRS and its predecessors (the Reactor Safeguards Committee and the Industrial Committee on Reactor Location Problems) independently reviewed and evaluated the licensing and operation of nuclear power plants and other major nuclear facilities. Because of the large number of projects and subjects reviewed, the ACRS established generic subcommittees. In the late 1970s, the ACRS formed the Waste Management Subcommittee to review increasing staff activities in the radioactive waste management arena (Lawroski and Moeller, 1979). The ACRS issued its first letter report on commercial LLW management in April 1976. Overall, the Committee issued more than 10 letter reports in this area. In April 1988, the Commission established the ACNW as a separate advisory committee to continue with this oversight (NRC, 1988b). The Committee held its first meeting on June 27, 1988. For its part, the ACNW has produced about 200 letter reports over its history. It issued its first letter report on

[87] FACA requires that Committee memberships be fairly balanced in terms of the points of view represented and the agency functions being performed. As a result, members of specific advisory committees tend to possess skills that parallel the program responsibilities of their sponsoring agencies (66 FR 37740).

LLW in August 1988 and has prepared about 30 additional letter reports on various LLW issues to date.

Table 21 includes a list of past ACRS and ACNW letter reports on various commercial LLW management topics. NUREG-1125 and NUREG-1423 contain copies of these letter reports and the exact text of the Committees' recommendations. The following section briefly summarizes the recommendations from those letters. Full-text versions of these letters are available on the Internet at *http://www.nrc.gov/what-we-do/regulatory/advisory/acnw.html.*

10.2 Summary of Past ACRS and ACNW Reviews

Both the ACRS and the ACNW have closely followed public health and safety issues associated with the management of commercial LLW. Most past ACRS and ACNW letters were in response to requests from the Commission, the Executive Director for Operations, or NRC program office staff, although others were in response to a perceived need identified by the staff, members of the public, licensees, or other agencies. The Committees have also followed international LLW practices and developments, as well as considerations arising from proposed or actual activities by the Agreement States. Both Committees have held individual briefing sessions and working group meetings dedicated to commercial LLW issues.

In addition to the broad experience of their members and supporting staff, the ACRS and ACNW have covered in their letters a wide band of selected commercial LLW management issues - ground-water monitoring, chemically mixed LLW, onsite storage, performance assessment, and site characterization - as well as specific technical topics such as LLW inventories and the suitability of certain types of LLW disposal containers. The Committees have also deliberated on broad topics concerning the regulation of LLW and the associated NRC programs.

The principal observations presented in past Committee letters can be generally classified into the following six areas:

- general LLW management issues
- the NRC's LLW regulatory framework
- ground-water monitoring
- chemically mixed LLW
- performance assessment
- waste package and waste form

10.2.1 General LLW Management Issues

Interim Report on Management of Radioactive Wastes (April 15, 1976). Early in the history of the civilian nuclear energy program, the NRC recognized the need for a plan to manage the radioactive wastes produced (NAS, 1957). The first NRC advisory committee letter commented on the adequacy of the regulations and technologies necessary for managing these wastes.[88] Although it was expected that the longer lived radioactive wastes would be destined for some yet-to-be-developed Federal repository (AEC, 1970), the disposal debate at the time had extended to other fuel cycle waste forms that had no clearly defined disposal solution (Hileman, 1982).

As a result of its reviews during 1975-76, the ACRS determined that the regulatory framework necessary to manage the radioactive wastes was not in place. The Committee also found that the technologies necessary for managing the wastes had yet to be perfected.

[88] The ACRS letter generally defined such wastes to include HLW, LLW, and other radioactive wastes containing TRU elements and fission products.

Table 21 **Past ACRS and ACNW Letter Reports Concerning LLW Management** (listed chronologically)

Letter Report Title	Date
Interim Report on Management of Radioactive Wastes	April 15, 1976
Report on Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle (NUREG-0116)	January 14, 1977
Low Level Solid Waste Generation	April 12, 1977
Report on Proposed Rule on "Licensing Requirements for Land Disposal of Radioactive Waste"	September 16, 1981
Establishment of *De Minimis* Values	February 13, 1984
ACRS Comments on the NRC Safety and Research Program and Budget for Fiscal Year 1987	June 11, 1985
ACRS Comments on the Definition of Low-Level Radioactive Waste	May 13, 1986
ACRS Comments on the NRC Safety and Research Program and Budget for Fiscal Year 1988	June 11, 1986
Additional Recommendations on the Development of *De Minimis* Levels	July 16, 1986
ACRS Comments on Various NMSS and RES Waste Management Topics: Report No. 1—ACRS Waste Management Subcommittee Comments on NMSS Radioactive Waste Management Program Report No. 6—ACRS Waste Management Subcommittee Comments on NRC Staff Policy Statement and Implementation of NRC Policy on Radioactive Wastes Below Regulatory Concern	August 13, 1986
ACRS Comments on "Standard Format and Content" (NUREG-1199) and "Standard Review Plan" (NUREG-1200), Guidance Documents for the Preparation of a License Application for a Low-Level Radioactive Waste Disposal Facility	March 9, 1987
ACRS Comments on Disposal of Mixed Waste	June 6, 1987
ACRS Comments on the Development of Radiation Protection Standards	November 10, 1987
ACRS Comments on Radioactive Waste Management Research and Other Activities	November 10, 1987
ACRS Comments on Selected FY 1988 NRC Radioactive Waste Management Research Programs	February 17, 1988
ACNW Comments on Proposed Branch Technical Position Concerning Environmental Monitoring for Low-Level Waste Disposal Facilities	August 9, 1988
ACNW Comments on Proposed Commission Policy Statement on Regulatory Control Exemptions for Practices Whose Public Health and Safety Impacts Are Below Regulatory Concern (BRC)	August 9, 1988
Proposed Policy Statement on Below Regulatory Concern	September 15, 1988
Suitability of High Density Polyethylene High Integrity Containers	September 16, 1988
Comments on Advance Notice of the Development of a Commission Policy on Exemptions from Regulatory Control for Practices Whose Public Health and Safety Impacts Are Below Regulatory Concern	December 30, 1988
Final Rulemaking on 10 CFR Part 61 Relative to the Disposal of Greater-than-Class C Low-Level Radioactive Waste	February 24, 1989
Management of Mixed Hazardous and Low-Level Waste (Mixed Wastes)	May 3, 1989

Letter Report Title	Date
Reporting Incidents Involving the Management and Disposal of Low-Level Radioactive Waste	July 5, 1989
Comments on Technical Position Paper on Environmental Monitoring of Low-Level Radioactive Waste Disposal Facilities	September 19, 1989
Low-Level Waste Performance Assessment Methodology	October 18, 1989
Commission Policy Statement on Exemptions from Regulatory Control	January 30, 1990
NRC Program on Low-Level Radioactive Wastes	January 30, 1990
Revision 1 of Draft Technical Position on Waste Form	September 6, 1990
Priority Issues in Radioactive Waste Management	January 21, 1991
Regulation of Mixed Wastes	February 28, 1991
Comments Regarding 10 CFR Part 61 Proposed Revisions Related to Groundwater Protection	June 27, 1991
NRC Capabilities in Computer Modeling and Performance Assessment of Low-Level Waste Disposal Facilities	December 2, 1991
Proposed Expedited Rulemaking: *Procedures and Criteria for On-Site Storage of Low-Level Radioactive Waste*	April 30, 1992
Source Term and Other Low-Level Waste Considerations	March 31, 1993
Review of Low-Level Radioactive Waste Performance Assessment Program	June 3, 1994
Private Ownership of Low-Level Waste Sites	February 6, 1995
Regulatory Issues in Low-Level Radioactive Waste Disposal Performance Assessments	June 28, 1995
Lessons-Learned from the Ward Valley, California, Low-Level Waste Disposal Facility Siting Process	August 10, 1995
Comments on SECY-95-201 and the NRC Activities Regarding Low-Level Radioactive Waste	December 29, 1995
Elements of an Adequate NRC Low-Level Radioactive Waste Program	July 24, 1996
Comments on Selected Direction-Setting Issues Identified in NRC's Strategic Assessment of Regulatory Activities	January 30, 1997
Time of Compliance for Low-Level Radioactive Waste Disposal Facilities	February 11, 1997
NRC Staff Research on Generic Post-Disposal Criticality at Low-Level Radioactive Waste	July 30, 1998
Branch Technical Position on Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities	August 2, 2000
Opportunities in the Area of Low-Level Radioactive Waste Management	December 27, 2005

To address these and other shortcomings, the ACRS recommended several actions, including the following:[89]

- the development of an updated (and integrated) radioactive waste classification system
- the development of both interim and long-term waste storage, siting, and handling criteria
- the establishment of an R&D program for the solidification of liquid radioactive wastes
- the creation of criteria for decommissioning of nuclear facilities
- the sponsoring of R&D for the management of nuclear wastes containing TRU elements and fission products

To ensure the achievement of these goals, the ACRS also recommended that the NRC assume an "aggressive leadership role in the development and implementation of a comprehensive long-term waste management program...."

Report on Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle (NUREG-0116) *(January 14, 1977)*. In 1976, the NRC published NUREG-0116, "Environmental Survey of Reprocessing and Waste Management Portions of the LWR Fuel Cycle" (Bishop and Miraglia, 1976). At the time, the NRC was licensing commercial LWRs, and the purpose of this report was to both fulfill the Commission's NEPA responsibilities and update the AEC's earlier 1972 generic study with detailed plant-specific data.

[89]The GAO (1977) later studied and commented on many of the issues the ACRS reviewed.

Following a review of the NUREG, the Committee noted that several areas of the report needed further discussion and evaluation. In reviewing the information on LLW, the ACRS commented that the NUREG's discussion about the environmental and public health impacts of LLW disposal was inadequate. Specific ACRS recommendations included the need for an evaluation of the migration of LLW with moderate- and long-lived radionuclides from SLB disposal facilities, sensitivity studies of the impact of LLW radionuclide inventory on dose calculations, an evaluation of the potential for and the consequences of radiological accidents during waste emplacement (disposal) operations, and better documentation of occupational exposures during SLB operations. Finally, the ACRS recommended that the NRC update NUREG-0116 to include an analysis of the impacts of TRU waste reclassification as HLW on a future Federal repository.

Low Level Solid Waste Generation *(April 12, 1977)*. Foremost among the responsibilities of the ACRS is the independent review and evaluation of license applications for the construction and operation of all commercial nuclear power plants. During one such review, the Committee learned that the volume of solid LLW expected to be generated from the operation of a PWR was about 200 m^3 (7000 ft^3) per year per reactor unit. An earlier NRC study (NRC, 1977c) estimated the volume of solid LLW generated to range from 400 to 800 m^3 (14,000 to 28,000 ft^3) per year per reactor unit. As this information was important for forecasting future LLW disposal needs, the Committee requested some clarification of the discrepancy.

ACRS Comments on Radioactive Waste Management Research and Other Activities *(November 10, 1987)*. During its 331st meeting, the ACRS reviewed, among other things, LLW management research activities within RES. In its letter following that meeting, the ACRS noted that the staff needed to better define the scientific bases for some of the requirements specified in various technical positions and the connection between these requirements and the NRC regulations they support. The ACRS noted that, in some cases, these requirements appeared to have been introduced only for the convenience of Agreement States or the operators of existing disposal facilities. The Committee believed that this practice called for careful examination to determine whether it established an undesirable precedent and whether the states' needs could be accommodated without the exercise of regulatory power.

As an example of this problem, the ACRS noted the staff's technical position on waste form undergoing development at that time.[90] The Committee commented that the technical position had not clearly defined the relationship between the waste form testing requirements and 10 CFR Part 61's performance objectives. The Committee recommended that the staff reexamine the fundamental bases of its technical position and its requirements, and ensure that the test and performance requirements pertained to the conditions likely to be found in SLB facilities. For example, the ACRS noted that the staff proposed leach testing of the waste form. However, they were not able to demonstrate any relationship between the proposed technical position and any 10 CFR Part 61 regulatory criteria. The Committee recommended that the staff either define the relationship or withdraw the proposed technical position. The ACRS also recommended that the technical position and the supporting analyses that form the bases of performance evaluation and acceptance of LLW forms readily available for public comment.

Following revisions that addressed the aforementioned concerns, in November 1990 the ACNW recommended publication of the final NRC technical position (NRC, 1991b).

[90]This discussion applied to an early version of NRC (1991b). See also Section 10.2.6 of this report.

In its November 1987 letter, the ACRS also referred to the (inevitable) decontamination and decommissioning of domestic nuclear power plants and the associated LLW generated from those activities. The Committee observed that the chemical complexity of those future waste streams required that the staff begin to anticipate potential problems in their management and to formulate a potential solution. To aid in this decisionmaking, the Committee recommended that the staff begin to engage outside consultants and/or RES staff (and its contractors).

Finally, the ACRS review of the RES programs at the time revealed only a very modest level of peer review of those programs. The Committee also noted that the ongoing request for proposal for the Federally Funded Research and Development Center (e.g., the Center for Nuclear Waste Regulatory Analyses) appeared to discourage the contractor from publishing its results in refereed journals, thereby disallowing the usual form of peer review. They recommended that in addition to encouraging journal publication, the staff should implement a careful, focused, and visible peer evaluation process of both the quality of the research results and their applicability to regulatory requirements. See, for example, the American Chemical Society and the Conservation Foundation (1985). It was also recommended that the staff should initiate such evaluations for each program to the extent feasible, should make the evaluations periodic, and should design them to provide clear objectives for the management of the research program.

ACRS Comments on the NRC Safety and Research Program and Budget for Fiscal Years 1987–88. In its June 11, 1985, letter reviewing the proposed LLW research programs for fiscal year (FY) 1987, the ACRS concluded that the current research budget was adequate. In its subsequent June 11, 1986, letter, the ACRS endorsed the proposed FY 1988 LLW research program, noting that the NRC was one of the few Federal agencies at the time conducting research in this field. The Committee remarked that the states urgently needed the results of the NRC's research studies because of the strict Congressionally-mandated timetable for developing new LLW disposal facilities. However, the ACRS noted that the program, as outlined, was the minimum necessary to meet NRC responsibilities in this area. The Committee recommended that the NRC allocate additional funds for research to develop the following:

- a technical basis for defining criteria for the designation of BRC materials
- radiation protection guidance for alternatives to the SLB of LLW
- an appropriate technical basis for managing GTCC LLW

ACRS Comments on Selected FY 1988 NRC Radioactive Waste Management Research Programs (February 17, 1988). During its 334th meeting, the ACRS met with NRC staff to discuss selected radioactive waste management research programs. These discussions included a review of research in the LLW area.

The Committee noted that the FY 1988 program plans did not include any research on the effects of organic chelating compounds on the behavior of LLW radionuclides. The Committee recommended that plans and resource allocations for FY 1988 be changed to include studies on this subject. Recognizing that such materials can have significant effects on radionuclide mobility and the increasing concerns about the management and disposal of chemically mixed LLW that frequently contain such materials, the Committee also reviewed the joint NRC/Canadian efforts to determine the adequacy and applicability of transport models for predicting the movement of radionuclides through groundwater and soils.[91] The Committee also made several recommendations concerning the use of sensitivity studies in these models. The Committee recommended that the work be completed in a timely manner to address the technical needs of the regional compacts evaluating and selecting candidate LLW disposal sites at the time.

The ACRS review included – and identified for further discussion – the development of reliable methods for the solidification of LLW, particularly in a concrete matrix, and improved environmental monitoring programs for LLW disposal sites.

Reporting Incidents Involving the Management and Disposal of Low-Level Radioactive Wastes (July 5, 1989). It had been previously reported that certain physical forms of LLW performed poorly in disposal facilities (e.g., National Research Council, 1976). To address this issue, the Committee considered recommendations to characterize the various LLW streams to allow for the identification and treatment (stabilization) of problematic waste form compositions. The development of a staff technical position on LLW forms (NRC, 1991b) partially addressed this issue. However, the Committee believed that a system for reporting performance incidents involving problematic LLW forms was also needed and that it should be developed in a timely manner. The Committee was concerned that the limitations in staff resources at the time be promptly addressed to avoid a highly undesirable delay in development of such a reporting system.

Priority Issues in Radioactive Waste Management (January 21, 1991). In response to a request from the Commission (dated December 10, 1990), the ACNW identified several waste

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[91]Results of these studies were later published as Robertson et al. (1987, 1989), Link et al. (1999), and Robertson et al.(2000).

management technical issues as deserving priority attention. In the area of LLW, the issues included the following:

- *Performance Assessments.* The Committee noted that although some guidance and a regulatory base existed for evaluating SLB facilities, few if any of the new facilities being proposed would be of this type. The Committee believed that the Agreement States, in particular, needed assistance in developing capabilities for assessing bunkered types of disposal facilities, and the deadlines mandated by the LLWPAA emphasized the urgency for such assistance. Included in these considerations, the Committee identified a need for improved capabilities to assess the magnitudes of the source terms for certain long-lived radionuclides, such as iodine-129 and carbon-14. The Committee noted that data on the quantities of these radionuclides that had been disposed in existing facilities were inaccurate.

- *Other Items.* The Committee considered other LLW-related issues, including the regulation of chemically mixed (radioactive) wastes, BRC policy, the decommissioning of nuclear power plants, and the evaluation of the performance assessment capabilities for newer types of LLW disposal facilities.

Private Ownership of Low-Level Waste Sites *(February 6, 1995).* In 1994, the Commission issued an ANPR (59 FR 39485) which indicated that it was considering a change to allow for private ownership of LLW sites as an alternative to the 10 CFR 61.59(a) requirement allowing only Federal or state ownership. In its review of this topic, the ACNW found no fundamental reasons why private ownership of LLW disposal sites should be prohibited but identified several related issues that, in its view, required deliberate and cautious action.

The first major issue concerned the need to ensure the protection of public health and safety and the environment. Earlier Commission policy discussions on adequacy and compatibility of Agreement State regulations with NRC's requirements had not included provisions for private ownership of waste disposal sites. In its February 1995 letter, the Committee advised the NRC to include explicit statements for pertinent requirements under the heading of adequacy and compatibility before proceeding with generic approval of private ownership. The Committee believed that the NRC should require effective and timely transfer of ownership to another responsible and capable entity, such as the state, when any changes in the private ownership provision for waste sites, including dissolution of the corporate entity, occurred. The Committee stated that the measure of adequacy and compatibility of Agreement State operations should include effective and frequent monitoring and evaluation of private entities responsible for waste sites.

The Committee noted that 10 CFR 61.7(a) ("Concepts") presents 500 years as the target reference for siting and intruder barrier considerations. However, disposed LLW could pose a significant hazard for periods that, under some conditions, could well exceed 500 years. The Committee noted that the Commission should expand the criteria to ensure that the state (or some governmental entity) maintain an active interest in the protection function of the disposal site for as along as the waste poses a hazard (as defined in the regulations).

The second major issue concerned the administrative procedures leading to privatization. The NRC's openness procedures for regulatory affairs provide ample opportunity for all interested parties to voice their views. The Committee observed that transferring LLW management accountability to a private corporate entity, with a likely modest life expectancy compared with the period of time the waste poses a hazard, would require administrative (licensing) procedures comparable to those already used by the Commission. The Committee noted that it had not obtained information that this was the case when the State of Utah first acted.[92]

In summary, although the Committee believed that private entities were potentially capable of meeting the long-term protection function requirements of LLW management, it thought that some type of governmental-oversight entity should ultimately be responsible for the long-term performance of an LLW disposal facility. Furthermore, the Committee believed that any decisionmaking by private operators of such sites should adhere to an open process not unlike the NRC's current administrative decisionmaking process.

Following review, the Commission decided not to amend 10 CFR 61.59(a).

Comments on SECY-95-201 and the NRC Activities Regarding Low-Level Radioactive Waste (December 29, 1995). In a September 14, 1995, SRM, the Commission requested the ACNW to provide comments on SECY-95-201, "Alternatives to Terminating the Nuclear Regulatory Commission Low-Level Radioactive Waste Disposal Program" (NRC, 1995c), including practicable alternatives to the proposed options and the Committee's views on the significant consequences of the available alternatives.

SECY-95-201 identified three options for the future of the NRC LLW program. Briefly, these options were as follows:

- Option 1: *Continue the program as currently in place*
- Option 2: *Reduce the program by eliminating or reducing various parts*
- Option 3: *Terminate all parts of the LLW program*

In SECY-95-201, the staff concluded that, based on statutory requirements and budget restrictions, Option 2 was the only practicable alternative. The Committee was unable to evaluate in detail the program as outlined in Option 2 because of the lack of specific resource allocations for various activities. The ACNW had a number of concerns with the conclusions of SECY-95-201. While recognizing the current budgetary constraints, the Committee concluded that it was in the national interest to maintain a centralized LLW program within the NRC, and it strongly recommended that the Commissioners prioritize the LLW program in relation to all activities within the agency. Further, the Committee noted that the use of terms such as "limited" and "essential" to describe the resources and activities under Option 2 was ambiguous. The Committee believed that the most important shortcoming of the SECY paper was its failure to address the fundamental question of what type of LLW program would be necessary and sufficient to satisfy the NRC's public health and safety mission.

Later in 1995, the Commission's Strategic Assessment and Rebaselining Initiative superseded further consideration of SECY-95-201.

Elements of an Adequate NRC Low-Level Radioactive Waste Program (July 24, 1996). The Committee prepared this letter report in response to a request from then-Chairman Jackson, who asked the Committee to review what would constitute an adequate LLW program. The Committee's earlier review of SECY-95-201 included a discussion of this topic.

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[92] Acting in its capacity as an NRC-approved Agreement State, the State of Utah had previously issued an exemption to the governmental land ownership requirement in its LLW regulations to Envirocare of Utah in March 1991 when the state issued a license allowing that private corporation to operate an LLW disposal facility on privately-owned land.

In its July 1996 letter, the Committee stated that an adequate NRC LLW program was one which would ensure that the processing, storage, and disposal of LLW, as defined in 10 CFR Part 61, would be carried out in accord with other NRC regulations (e.g., 10 CFR Part 20) and that the current and future impact of such activities would not represent an excessive risk to the affected population or the environment. Further, the Committee observed that including GTCC LLW as defined in 10 CFR Part 61 and mixed waste in such a program would also be desirable. Under such an expanded scope, the program would include NARM and NORM, wastes from uranium recovery and processing, wastes formed by the inadvertent concentration of contaminants (e.g., sewage, baghouse dust), and wastes derived from decontamination and decommissioning activities.

***Comments on Selected Direction-Setting Issues Identified in NRC's Strategic Assessment of Regulatory Activities** (January 30, 1997).* The Commission undertook a four-phase strategic planning exercise in 1995 known as the Strategic Assessment and Rebaselining Initiative (NRC, 1996d). This planning exercise was described earlier in Section 9.3 of this report. The initiative's principal focus was the identification of key strategic issues associated with the NRC's primary responsibility to protect public health and safety and the environment. These key issues were called DSIs, and DSI 5 applied to the NRC's LLW program.

In its January 30, 1997, letter, the ACNW commented on DSI 5 and other cross-cutting waste management issues outlined in the strategic planning documents. The ACNW recommended that the Commission adopt Option 2 as set forth in SECY-95-201 and "assume a strong regulatory role in [a] national LLW program...." The Committee's other recommendations included the following:

- A number of waste types were missing from the discussion. In its general introductory comments, the Committee noted its concern about the omission of DSI cross-cutting issues such as the management of chemically mixed wastes and GTCC LLW. The Committee believed that the agency's strategic planning needed to address these issues adequately.

- The NRC's acceptance of long-term storage of LLW, although attractive as a practical solution to a (then) current problem, may not be acceptable to the Nation. The Committee noted that the current national policy is to provide permanent disposal by the present generation in a manner that does not jeopardize current or future public health and safety. The DSI paper did not adequately address the requirements for implementing long-term storage of commercial LLW. The Committee was also concerned about the rather favorable light placed on interim waste storage in the DSI paper, which was presumably because, to date, no incident had been reported as a result of storage at the originating (generating) site. However, the Committee also noted that no evidence exists that onsite storage can be effective over the expected life of the waste and that the proliferation of storage sites enhances the risk.

- The Committee suggested that caution be exercised in using "rules of thumb" to define waste types in terms of the length of time over which they may be hazardous. In view of the absence of a *de minimis* position on radioactivity (Section 3.5 of this report) and the broad application of the linear no-threshold view of the human health effects of radiation, the Committee believed that rules of thumb were a significant oversimplification.

- Finally, the Committee questioned the appropriateness of using DOE sites as potential disposal sites for commercial LLW. The selection of existing DOE sites did not involve the application of criteria used in siting and licensing commercial disposal facilities, and evidence was lacking that these sites could meet the standards and regulations in effect.

In conclusion, the Committee recommended Option 2 but encouraged additions to develop a more comprehensive definition of LLW and to evaluate the potential implementation and impact of assured storage with adequate protection and termination procedures.

10.2.2 The NRC's LLW Regulatory Framework

Report on Proposed Rule on "Licensing Requirements for Land Disposal of Radioactive Waste" (September 16, 1981). In July 1981, the NRC staff proposed its LLW disposal regulations at 10 CFR Part 61 (46 FR 38081). In its September 1981 letter to the Commission, the ACRS provided both general and specific comments on the proposed rule, as noted below:

<u>General Comments</u>

- *Adequacy of Proposed Rule.* The ACRS observed that the proposed rule contained criteria to ensure improvement in the siting, design, and operation of near-surface LLW disposal facilities. The Committee recommended that the staff continue to seek better containment, stabilization, and immobilization of LLW as well as completion of the criteria for deeper land burial and disposal in mined cavities. The Committee also recommended an evaluation of the possible disposal of such wastes at sea.

  In addition, the ACRS recommended that the Commission address the processes that result in the production of commercial LLW. In this regard, the Committee recommended that the Commission look at techniques both for reducing the volumes of wastes generated and for ensuring that the wastes produced are in, or can be converted to, a form amenable to safe disposal.

- *Applicability to Existing Disposal Facilities.* The proposed rule stated that many of the proposed operational requirements were currently in effect at licensed LLW disposal facilities and that such facilities should have no difficulty in complying with the proposed requirements. However, the ACRS observed that there were no proposed requirements for sites that had ceased operating because of earlier performance problems. The Committee noted in its letter that the NRC staff had stated that the regulatory guides issued in support of the proposed rule would enumerate methods for decommissioning those facilities. The Committee suggested that development of satisfactory guidance for such actions could be difficult as many decommissioning sites at the time contained wastes that included plutonium and other long-lived radionuclides that had already been mobilized because they had come into contact with water.

- *Types and Quantities of Wastes Subject to Disposal.* The ACRS observed that development of the proposed rule revealed certain deficiencies in available LLW census data. It noted that this was particularly true with respect to the compilation of detailed inventories on the quantities and specific radionuclide concentrations in the LLW buried at existing disposal sites. The Committee noted that the NRC staff was, at the time, attempting to compile the needed data. With respect to this effort, the Committee observed that the development of instrumentation to identify and assess radionuclide concentrations in waste packages would also be necessary. The Committee suggested that such data were essential to a clear understanding of current LLW disposal practices and the impact of various regulatory actions, particularly the influence of the establishment of *de minimis* concentrations for selected radionuclides in specified types of wastes. The Committee also noted that the data were essential to assess the impact of various restrictions on the types of wastes acceptable for disposal at a given site.

Specific Comments

- *Timespans for Various Requirements.* The ACRS reported that the proposed rule lacked specificity concerning the timespan during which the various design requirements would apply. They recommended that the proposed rule clearly state that restrictions - such as those pertaining to floods, erosion, and water drainage - would apply through the time of site closure as well as the period of institutional control. However, the Committee saw little need for a specific instruction to observe long-term tectonic changes potentially affecting the site.

- *Avoidance of Soil Subsidence.* The proposed rule implied that the waste form plays a major role in the soil subsidence that frequently occurred at land disposal facilities in the past. Since subsidence results from a variety of factors, including primarily the manner in which the waste packages are placed in the disposal trenches, the Committee recommended that the Commission reevaluate and revise the proposed rule on this issue.

- *Restrictions on Types of Wastes.* The proposed rule contained a number of limitations on the types of wastes that could be disposed of in a near-surface disposal facility. These included restrictions on pyrophorics, explosives, wastes that generate toxic gases, and other wastes. The proposed rule also set requirements on the "stability" of the wastes which, in the Committee's opinion, lacked clear definition as well as specification of the minimum compressive strength for the wastes, which could unduly increase the volumes to be buried. The Committee recommended that the staff carefully assess the proposed restrictions and requirements for both their enforceability and their overall implications.

- *Disposal of Chelating Agents.* The proposed rule did not allow the disposal of wastes containing greater than 0.1 percent chelating agents in near-surface land facilities. Such agents were present in a wide variety of radioactive wastes at the time (for example, in decontamination solutions), and the ACRS remarked that the proposed requirement could exclude many wastes from burial. Based on earlier discussions with NRC staff, the Committee noted that the staff's intent was not to exclude such wastes from burial but to enable their disposal subject to NRC approval. The Committee, therefore, recommended that the proposed rule emphasize that the disposal of chelating-agent-containing wastes could be considered on a case-by-case basis.

***ACRS Comments on the Definition of Low-Level Radioactive Waste** (May 13, 1986).* On January 15, 1986, Congress passed amendments to the LLWPA. In those amendments, Congress authorized the NRC to develop a regulatory definition of LLW. In its May 1986 letter, the ACRS recommended that the Commission expand the definition of LLW to include NARM wastes. In making this recommendation, the Committee stated that it was important to control such wastes to protect public health and safety.

***ACRS Waste Management Subcommittee Comments on NMSS Radioactive Waste Management Program** (Report No. 1 — August 13, 1986).* Section 8 of the LLWPAA directed the NRC to identify methods for the disposal of LLW other than SLB and to publish technical guidance regarding licensing of those facilities. The staff initially complied with this provision by publishing several reports in the NUREG/CR-3774 series (Bennett et al., 1984; Bennett, 1985; Bennett and Warriner, 1985; Miller and Bennett, 1985; Warriner and Bennett, 1985).

In March 1986, the staff made a draft BTP available for public comment that identified and described alternatives to SLB. See NRC (1986a). At a July 1986 meeting of the Waste Management Subcommittee, the staff briefed the ACRS on its proposed final guidance. In its August 1986 comments to the Commission, the ACRS recommended that the staff poll the Agreement States to determine which SLB alternatives they would prefer. The Committee believed the responses could help reduce the number of approaches to be evaluated. They also recommended that the staff solicit recommendations from EPA for selecting which alternatives to consider.

The ACRS suggested that after compiling this information, the staff should group the alternatives and develop applicable disposal criteria on a generic basis.

De Minimis Position and the Below Regulatory Concern Policy Statements. As noted earlier in this report, the LLWPAA required the NRC to establish standards for determining when radionuclides in waste streams are in sufficiently low concentrations or quantities as to be BRC and, therefore, not subject to NRC regulation. In response to the statute, the staff developed a *de minimis* position in conjunction with the 10 CFR Part 61 rulemaking. Shortly thereafter, the staff issued two BRC Policy Statements. Section 3.5 of this report discusses both of these activities.

The letter reports listed in Table 22 contain the ACRS and the ACNW comments, in whole or in part, on the staff's attempts to establish minimum exemption levels for the management of materials containing low levels of radioactive materials.

***ACRS Comments on "Standard Format and Content" (NUREG-1199) and "Standard Review Plan" (NUREG-1200), Guidance Documents for the Preparation of a License Application for a Low-Level Radioactive Waste Disposal Facility** (March 9, 1987).* As noted earlier in this report, the NRC staff developed several documents to aid in the implementation of 10 CFR Part 61. NUREG-1199 (NRC, 1991a) details the components and information needed in a 10 CFR Part 61 license application. NUREG-1200 (NRC, 1994a) provides guidance on the process the staff would use to review that license application.

After reviewing early versions of these two guidance documents, the ACRS commented that both were overly detailed and stringent. The Committee noted that both required prospective applicants to submit information and to develop capabilities that were not warranted by the public health risks associated with the operation of an LLW disposal facility. While considering the guidance documents too detailed in some respects, the Committee also found that they were not clear enough in other areas.

Table 22 Past ACRS and ACNW Letter Reports Concerning *De Minimis* Issues and Below Regulatory Concern Policies

Letter Report Title	Date
Establishment of *De Minimis* Values	February 13, 1984
ACRS Comments on the NRC Safety and Research Program and Budget for Fiscal Year 1987	June 11, 1985
Additional Recommendations on the Development of *De Minimis* Levels	July 16, 1986
ACRS Comments on Various NMSS and RES Waste Management Topics: Report No. 6—ACRS Waste Management Subcommittee Comments on NRC Staff Policy Statement and Implementation of NRC Policy on Radioactive Wastes Below Regulatory Concern	*August 13, 1986*
ACRS Comments on Radioactive Waste Management Research and Other Activities	November 10, 1987
ACNW Comments on Proposed Commission Policy Statement on Regulatory Control Exemptions for Practices Whose Public Health and Safety Impacts Are Below Regulatory Concern (BRC)	August 9, 1988
Proposed Policy Statement on Below Regulatory Concern	September 15, 1988
Comments on Advance Notice of the Development of a Commission Policy on Exemptions from Regulatory Control for Practices Whose Public Health and Safety Impacts Are Below Regulatory Concern	December 30, 1988
Commission Policy Statement on Exemptions from Regulatory Control	January 30, 1990
Priority Issues in Radioactive Waste Management	January 21, 1991
Regulation of Mixed Wastes	February 28, 1991

The Committee noted the definition of a "buffer zone" as one example. The Committee also noted that the guidance documents contained requirements that could exceed current technical capabilities, such as the verification of the LLW class of a given waste sample and a determination of whether it contains chemically hazardous materials. Lastly, the ACRS noted that discussions of certain topics (such as environmental monitoring) were so dispersed throughout the texts of the documents that they were too difficult to follow.

In closing its March 1987 letter, the ACRS noted that both guidance documents cited the ICRP Publication 30 series as the basis for associated radiation dose assessments although the referenced 10 CFR Part 61 regulations were based on ICRP Publication 2 (ICRP, 1959) and the standards for radiation protection prescribed in 10 CFR Part 20. The Committee recommended that the staff simplify and clarify NUREG-1199 and NUREG-1200. As part of that clarification effort, ACRS suggested that the staff examine comparable EPA reports prepared for the review of disposal facilities for chemically toxic (i.e., RCRA) wastes.

In the years since the Committee's 1987 comments, the staff has twice revised both NUREG-1199 and NUREG-1200.

Final Rulemaking on 10 CFR 61 Relative to the Disposal of Greater-than-Class C Low-Level Radioactive Waste (February 24, 1989). In 1988, the Commission proposed amendments to 10 CFR Part 61 that would require the deep geologic disposal of GTCC LLW unless the Commission approved an alternative means of disposal elsewhere. At its 17th meeting, held in

1989, the staff briefed the ACNW on the final proposed rule (NRC, 1988b). Meeting discussions centered around the public comments received, and the staff's review and disposition of those comments. Following this review, the Commission approved amendments at 10 CFR 61.55(b)(2)(iv) to permit the disposal of GTCC LLW in an HLW geologic repository licensed under 10 CFR Part 60 or some other type of approved disposal facility design (NRC, 1989b). Subject to certain recommendations, the Committee agreed with the proposed final rule. (Also see Section 8.1 of this report.)

NRC Program on Low-Level Waste (January 30, 1990). By the early 1990s, the NRC's 10 CFR Part 61 regulatory framework was in place and supported by a considerable amount of implementing guidance. Consistent with direction from the LLWPAA, DOE and EPA had also undertaken the development of additional technical information applicable to the management of commercial LLW.

At its 16th meeting, the ACNW learned the status of current LLW activities. As a result of that briefing, the Committee produced a letter with several recommendations. It first recommended that the Commission give more attention to the generator side of the LLW program with a focus on processes affecting the types of LLW in the waste stream. The Committee hoped to identify potential efficiencies in reducing the quantities of LLW being generated. The Committee believed that a "systems approach" to the management and disposal of LLW was necessary and could yield considerable dividends (i.e., lower disposal costs). (For the NRC's part, it observed the need for closer coordination between the cognizant program offices within the agency.) The Committee also noted the need for greater integration of all pertinent technical information from all cognizant agencies in order to create a "road map" providing comprehensive guidance to licensees. Both referenced and annotated, such guidance would contain key regulatory guides, technical positions, and NUREGs, as well as other technical information developed by other agencies with a role in the management of commercial LLW. The Committee also recommended that the staff prepare a report on current operating experiences at existing LLW facilities and use the insights gained to improve the NRC's regulatory responsibilities. Lastly, the Committee recommended that the Commission accelerate the process for developing new commercial disposal facilities.

***Proposed Expedited Rulemaking: Procedures and Criteria for On-Site Storage of Low-Level Radioactive Waste** (April 30, 1992).* At its 42nd meeting, the Committee learned of a plan for developing a rule that would allow for the long-term storage of commercial LLW by existing NRC licensees. The Committee endorsed the rulemaking plan and its objectives. However, although the rulemaking plan addressed the wastes to be generated after 1996, the ACNW was concerned about wastes generated in the more immediate post-1992 timeframe, noting that there were indications that all existing LLW disposal sites, except Hanford, could stop accepting radioactive waste by the end of 1992. The Committee concluded that if this scenario came true, interim storage of LLW would become necessary. The staff never implemented its rulemaking plan.

***Regulatory Issues in Low-Level Radioactive Waste Disposal Performance Assessment** (June 28, 1995).* This letter was a continuation of the Committee's earlier review of NRC's LLW performance assessment program. In developing the performance assessment methodology outlined in draft NUREG-1573, the staff identified areas in the 10 CFR Part 61 regulation pertaining to LLW performance assessment for which supplemental advice was thought to be necessary. The staff sought the Committee's advice on its proposed resolution of stakeholder comments - received during a 1994 public workshop on the draft NUREG - on the following four regulatory issues:

(1) consideration of site conditions, processes, and events in an LLW performance assessment

(2) performance of engineered barriers

(3) timeframe for conducting an LLW performance assessment

(4) treatment of sensitivity and uncertainty in an LLW performance assessment

The staff later expressed its views on these regulatory issues, which the ACNW highlighted, and sought direction from the Commission in SECY-96-103 (NRC, 1996c). Table D-2 (in Appendix D) to this report contains a more detailed discussion of the recommendations and guidance provided in NUREG-1573.

10.2.3 Ground-Water Monitoring

Environmental Monitoring for LLW Disposal Facilities. In a November 1987 *Federal Register* notice (NRC, 1987b), the NRC staff made available for public comment a draft BTP on the subject of the 10 CFR 61.53(c) environmental monitoring requirements for LLW disposal facilities. See 52 FR 42486. Following the request for comments, the staff interrupted work on the BTP because of resource limitations. In its comments to the Commission dated August 9, 1988, the ACNW recommended that the staff complete its work on the BTP and issue the final guidance. However, in making its recommendation, the Committee also advised that the overall purpose of the staff's technical position in this area needed to be clarified to indicate whether it was prepared to provide guidance on monitoring policy or to prescribe detailed monitoring requirements.

After a brief interruption, staff work on the development of the environmental monitoring BTP continued, but under the new title of a "technical position paper." Following a second review, the ACNW noted in its September 19, 1989, letter, that the renamed guidance was acceptable for publication. However, the staff never finalized the guidance document but later identified it as a candidate area for a potential rulemaking in the future. See Table 20.

As noted in Section 9.2 of this report, in recent years RES has sponsored many research projects and public workshops on environmental monitoring and modeling. Many of these products are listed in Appendix E to this report.

Comments Regarding 10 CFR Part 61 Proposed Revisions Related to Ground Water Protection (June 27, 1991). In a September 6, 1990, letter, the ACNW recommended that the staff publish the revised NRC technical position on waste form (NRC, 1991b). Along with the recommendation, however, the Committee expressed several concerns, including the need to revise 10 CFR Part 61 regulation to show more direct emphasis on the resistance of LLW forms to leaching by percolating groundwater. The Commission subsequently requested that the Committee justify its position by evaluating the efficacy of the existing 10 CFR Part 61 in meeting its concerns.

In a subsequent meeting with staff, the Committee reviewed the history and performance experiences of earlier LLW disposal facilities, particularly as they related to the migration of radioactive materials. It noted that the staff considered this past experience in scoping the 10 CFR Part 61 EIS and developing the subsequent LLW regulation. The Committee also learned of the staff efforts at the time to undertake detailed studies of contaminant flow and transport phenomena as part of a broader LLW performance assessment effort, later to be documented in NUREG-1573. This emerging work assured the Committee that the staff would provide additional insights into ground-water protection issues. Lastly, the Committee held a brainstorming session with NRC staff members and their technical assistance contractors at the time to explore options that might improve radionuclide retention in, or retard radionuclide migration from, LLW waste forms.

On the basis of these interactions, the Committee set aside its suggestion that the staff revise 10 CFR Part 61 to explicitly include a requirement for LLW waste form performance as a means of enhancing ground-water protection.

10.2.4 Chemically Mixed Radioactive Waste

ACRS Comments on Disposal of Mixed Waste (June 6, 1987). Although not addressed in detail in this report, chemically mixed LLW is subject to dual regulation under EPA's RCRA regulations. During the 326th meeting of the ACRS in June 1987, the staff described its efforts to develop jointly with the EPA a definition of, and acceptable methods for regulating the disposal of, chemically mixed radioactive waste. As a result of that briefing, the Committee had some concerns about the interpretation of the definition of "mixed waste." It noted that if a strict interpretation resulted in a large increase in the wastes classified within this category, it could have a negative impact on the disposal of wastes from many facets of the nuclear industry. The ACRS recommended that the staff address specific questions to resolve this issue, including the procedures and schedule for licensing facilities where such wastes could be disposed, the role of Agreement States in such activities, and how such wastes would be handled in the interim.

Management of Mixed Hazardous and Low-Level Radioactive Wastes (Mixed Wastes) (May 3, 1989). Following meetings with NRC staff and Nuclear Management and Resources Council (NUMARC [93]) representatives, the ACNW offered several recommendations to the Commission regarding the management of chemically mixed LLW. The Committee believed that the Commission should assign additional resources to study this issue, that its resolution was primarily institutional, and that the problems caused by dual jurisdiction were solvable [although at the time most knowledgeable institutions seemed to recognize that any disposal facility meeting NRC regulatory requirements was also capable of meeting EPA criteria for the disposal of hazardous (nonradioactive) wastes].

The Committee also observed that the staff had overlooked the management of chemically hazardous GTCC LLW, NARM, and NORM and needed to give attention to these areas.

Regulation of Mixed Wastes (February 28, 1991). Following the May 1989 letter from ACNW, OTA (1989) published a comprehensive report on the status of the national LLW program. That report included an examination of chemically mixed LLW issues, and it noted the lack of mixed waste treatment options, access to mixed waste disposal facilities, and conflicting (and inconsistent) EPA and NRC regulations. At the request of then-Commissioner Curtis, the ACNW reviewed the comparability of protection afforded by NRC and EPA regulations when applied to the disposal of chemically mixed LLW. The Committee responded to the request by conducting a working group meeting on the subject in December 1990 and dedicating additional time to the matter at subsequent ACNW meetings.

Following up on its May 1989 letter on chemically mixed LLW, the Committee reported that an industry-sponsored study (NUMARC, 1990) seemed to indicate that a facility built in conformance with 10 CFR Part 61 was slightly superior to a facility built in conformance with the EPA RCRA regulations at 40 CFR Part 264, "Standards for Owners and Operators of

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[93] In 1994, NUMARC merged with the U.S. Council for Energy Awareness, the American Nuclear Energy Council, and the nuclear division of the Edison Electric Institute to form the Nuclear Energy Institute.

Hazardous Waste Treatment, Storage, and Disposal Facilities." However, the NRC staff stated that certain features of any disposal facility designed to those regulations, such as the requirement for a double liner and the leachate collection and retention provisions, "appear to offer enhanced protection of groundwater, at least temporarily...." The Committee also noted that the then proposed EPA LLW standard - 40 CFR Part 193, "Radiation Protection Standards for Low-Level Radioactive Waste Disposal" (Gruhlke and others, 1989), which included a "subsystem requirement that groundwater contamination be limited so that no offsite person will receive an effective dose rate greater than 4 mrem/yr, may be a potential important attribute of the EPA regulations that is important...." The ACNW February 1991 letter discussed several other considerations. The Committee noted that most of the chemically mixed LLW generated in the United States were at DOE facilities. The Committee suggested, therefore, that a reasonable solution might be to have commercially generated mixed wastes assigned to DOE (similar to the responsibility already given to DOE for GTCC LLW).

The Committee's February 1991 letter also contained the following:

- The Committee recommended an action to establish a category of mixed wastes that was below BRC. Such wastes could be reclassified as hazardous wastes and regulated only by the EPA. The Committee understood at the time that more than 90 percent of biomedical wastes would fall into this category.

- Concurrently, the Committee recommended that the EPA be encouraged to modify its regulations to develop and implement *de minimis* criteria for hazardous and mixed wastes. The NRC should also encourage the EPA to modify its regulations to permit interim storage of mixed wastes awaiting disposal and to develop standards for the treatment of such wastes.[94]

- The Committee also believed that a combination bunker (i.e., AGV) disposal for Class B and C LLW, along with a leachate collection system in place for at least as long as the EPA regulations would require, could meet the combination of disposal requirements for mixed wastes specified by the NRC and EPA.

In conclusion, the Committee strongly believed that adopting its proposal would significantly reduce the volume of chemically mixed LLW produced. By virtue of lower production volumes, the Committee believed that waste generators would realize a net financial savings. This cost reduction, combined with some level of regulatory simplification, would reverse "the debilitating trends by scientists to avoid the use of radioactive and hazardous materials in important research...."

10.2.5 Performance Assessment

Low-Level Waste Performance Acceptance Methodology (October 18, 1989). One of the staff's first tasks after the establishment of the NRC LLW program was the development of an LLW performance assessment strategy. See Starmer et al. (1988). At its 14th meeting, held in October 1989, the staff briefed the ACNW on that strategy. In its comments to the Commission, the Committee observed that the strategy paper was well written and of value. The Committee recommended that the strategy be issued as a technical position or guidance paper or in another suitable form to ensure that it received the attention it deserved. The Committee also recommended that dose limits be expressed in

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[94]In 2003, the EPA published an ANPR discussing alternatives for the disposal of chemical wastes containing low concentrations of radioactive material (68 FR 65119). One of the alternatives cited in the ANPR was the use of RCRA Subtitle-C disposal technology for such wastes.

both metric and English units and that the paper include the concept of effective dose equivalent. However, the staff noted that resource availability was minimal at the time, and the Committee urged the Commission to make additional resources available to support this program.

NRC Capabilities in Computer Modeling and Performance Assessment of Low-Level Waste Disposal Facilities (December 2, 1991). The ACNW prepared this letter report in response to several questions by then-Commissioner Rogers. The Committee discussed its response to the differences in capabilities in addressing the management and disposal of HLW and LLW. The letter addressed HLW disposal capabilities separately. After several pages of discussion which provided specific comments and addressed computer modeling capabilities, the ACNW concluded that the NRC staff was developing sound computer modeling and performance assessment capabilities and was assembling a competent group of analysts. The Committee also thought that the staff should develop an overall strategy document for the program, upgrade existing computer hardware and software, and establish closer ties with other groups involved in related activities (both nationally and internationally). In addition, the Commission should provide adequate resources to achieve the Committee's recommendations. Lastly, the Committee believed there should be timely action on its recommendations in light of impending needs to license new LLW disposal facilities.

Review of the Low-Level Radioactive Waste Performance Assessment Program (June 3, 1994). This letter summarized the Committee's views based on discussions and presentations by the staff over a 3-month period. It commented on the capability of the staff's LLW performance assessment program applied to the review of new disposal facilities as well as the development of the draft BTP – later documented in NUREG-1573 — which was undergoing development at the time.

Committee comments on the staff LLW performance assessment capability included the following:

- The staff had a sound and functional understanding of the bases of comprehensive performance assessments. The staff was also knowledgeable and appeared to have the necessary resources for developing its capability.

- The staff should seek ways to demonstrate that its performance assessment results agreed with actual data obtained from operating sites. Although such data could be difficult to obtain, the benefits from such a demonstration would be worth the effort.

- The staff should develop a rational basis for the scope and depth of its required capability in performance assessments, focusing on its ability to review an LLW performance assessment for credibility and completeness.

- The staff should make risk calculations from an LLW performance assessment using, to the extent feasible, dose models that the NRC applied elsewhere for such purposes. The staff's presentations at the time indicated no such consistency.

- The Committee agreed with, and strongly supported, the proposed use of probabilistic techniques in the performance assessment process. These techniques are essential to capture uncertainty, to clearly delineate the current state of knowledge, and to serve as a guide to the acquisition of additional data.

In its June 1994 letter report, the Committee also offered detailed comments on the draft BTP for the staff to consider.

Time of Compliance for Low-Level Nuclear Waste Disposal Facilities (February 11, 1997). In this letter, the ACNW built on the principles it had outlined in an earlier Committee letter on the timespan of regulatory compliance for the proposed Yucca Mountain HLW repository (Pomeroy, 1996) and recommended a two-part approach to establishing a timeframe over which compliance with the LLW disposal regulation would be demonstrated. The first part utilized a site-specific timespan based on an analysis to determine the time at which release and transport of the more mobile radionuclides produce a peak dose to the critical population group. The second part was a qualitative evaluation, not requiring a specific measure of compliance, which identified any significant deficiencies in the performance of the disposal system.

The ACNW noted that the current NRC LLW regulation did not specify the length of time (the time period of regulatory compliance) during which the calculated dose should be compared with the specified radiation standard. The Committee observed that the rule was concerned with the minimum times of analyses. For example, 10 CFR Part 61 at Section 61.7 ("Concepts") states that "in choosing a disposal site, characteristics should be considered in terms of the indefinite future and evaluated for at least a 500-year time frame...." The Committee suggested that this statement was, in part, the origin of the misconception that 10 CFR Part 61 is a 500-year rule that only requires a demonstration of compliance for this time period. At the time, draft NUREG-1573 recommended a time specification of 10,000 years, which the 10 CFR Part 61 DEIS scoping calculations (NUREG-0782) also included. However, the Committee noted that the 10 CFR Part 61 FEIS (NUREG-0945) did not include (specify) a compliance or time period during which the required analyses were to be performed.

The final published version of NUREG-1573 (NRC, 2000) contains the staff's views and recommendations on an appropriate timeframe for an LLW performance assessment. This issue is discussed in more detail in Appendix D to this report. (See Table D-1.)

The NRC Staff Research on Generic Postdisposal Criticality at Low-Level Radioactive Waste Facilities (July 30, 1998). This letter report, drafted in response to SECY-98-010, "Petition for Envirocare of Utah to Possess Special Nuclear Material in Excess of Current Regulatory Limits" (NRC, 1998a), directed the NRC staff to consult with the ACNW on whether to pursue a research project to evaluate the potential for postclosure criticality as a result of hydrogeochemical processes reconcentrating uranium at LLW disposal facility sites.

On the basis of the information provided by the staff at the time, the ACNW agreed that the likelihood of reconcentration in an LLW disposal facility was remote and the consequences of any resulting criticality appeared similarly minimal. The Committee could not conclude that any significant research on postclosure criticality was warranted. However, it did believe that much could be learned from limited additional research, namely a quantitative risk (performance) assessment of a specific site. At the time, the analyses performed to date contained elements of risk assessment but lacked consistency of application in the propagation of realistic uncertainties throughout the analytical models.

Branch Technical Position on a Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities (August 2, 2000). Following publication of a draft for public comment and resolution of the comments received (NRC, 1997a), the staff briefed the ACNW on the final proposed NUREG-1573 at the Committee's 119th meeting. It its subsequent August 2000 letter to the Commission, the ACNW recommended issuance of the NUREG in final form. The Committee also provided some comments for the Commission to consider, which the staff responded to in Appendix E to the final NUREG. Table D-3, in Appendix D to this report, summarizes the Committee's comments and the staff's responses thereto.

Lessons Learned from the Ward Valley, California, Low-Level Waste Disposal Facility Siting Process (August 10, 1995). In 1995, NAS issued its report examining the validity of seven site-suitability issues raised by staff geologists at the USGS regarding the Ward Valley LLW disposal site.[95] The ACNW reviewed the report (National Research Council, 1995b) and a member of the NAS panel made a presentation to the Committee on this topic at the 75th meeting of the ACNW. That panel member identified key lessons learned from the Ward Valley peer review, which the Committee also endorsed in its letter. Foremost among these lessons learned was that future LLW siting activities should ensure that information developed on the site characteristics would be accompanied, preferably from its initiation, by an independent, ongoing peer review focused on the scientific and technical quality and completeness of the field investigations, analytical programs, and planning for the work that accompanies them. A recognized and demonstrably competent panel of experts should conduct such a review.

The Committee also recognized at the time that any future LLW sites were likely to be developed under the purview of the Agreement States. Nevertheless, for those states in which a disposal facility is contemplated, the developer should provide a plan that describes the process of forming such peer review panels and the way in which their output could best be used in future decisionmaking.

10.2.6 Waste Package and Waste Form

Suitability of High-Density Polyethylene High Integrity Containers (September 16, 1988). The NRC's LLW regulation at 10 CFR 61.56(b) ("Waste Containment") requires the use of a waste container of sufficient structural stability for the disposal of Class B and C LLW. NUREG-1199 (NRC, 1991a) gives guidance on demonstrating that the 10 CFR Part 61 structural stability requirement has been met. The staff has previously investigated the suitability of fabricating HICs from high-density polyethylene (HDPE) - a type of durable plastic. Based on presentation material from its third and fourth meetings, as well as a review of selected technical documents, the Committee stated in its letter that the HDPE HIC designs under consideration at the time would have difficulty in meeting the NRC's mechanical properties criteria for Class B and C waste containers. The Committee recommended coupling (integrating) HDPE with another suitable material to satisfy the pertinent NRC regulatory criteria. The Committee recommended that the staff bring to closure the HDPE HIC studies for previously submitted designs, thus allowing the industry to better plan its response and further action.

Revision 1 of Draft Technical Position on Waste Form (September 6, 1990). A key feature of the NRC' s 10 CFR Part 61 regulation is the waste form stability requirements set forth in 10 CFR 61.56(a). As noted earlier in this report, the Commission established these requirements to address some past performance issues at early LLW disposal facilities. Following publication of its final LLW rule, the staff published guidance, in the form of a technical position, on suggested approaches (including testing

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[95]In 1993, the State of California approved a license to construct a new LLW disposal facility in Ward Valley on lands held by the Bureau of Land Management (BLM). The state later asked the U.S. Department of the Interior (DOI) to transfer those lands to state control to allow for the construction of the disposal facility. While DOI was considering the transfer, three USGS geologists (acting as individuals rather than in an official Government capacity) expressed seven concerns about the suitability of the site. Before making a decision to transfer the BLM's land, DOI asked NAS to convene a committee to act as a peer review of the validity of the disputed issues. See also GAO (1997) and Andersen (1998).

procedures) for demonstrating compliance with the requirements. See NRC (1983b). Later, in parallel with the staff's efforts, NUMARC (1988) prepared a technical basis document that potential licensees could use to support their compliance demonstrations.

In June 1990, the staff prepared a revised version of the 1983 technical position. In its September 1990 letter, the ACNW noted that the 1990 revision represented a significant expansion of the previous version and reflected many of the points that the Committee called to the attention of the NRC staff during previous ACNW and ACRS subcommittee meetings. Taking into account the significance that the quality (stability) of the LLW form has to public health and safety (i.e., performance of the LLW disposal facility), the Committee concluded that the revised technical position (NRC, 1991b), when fully implemented, would serve as a useful guide in the evaluation of waste forms used in LLW disposal.

Nevertheless, the Committee did identify the following areas in which the staff could still improve the revised technical position:

- 10 CFR Part 61 lacks a requirement for a specified resistance of the waste form to leaching of radionuclides by groundwater. The NRC should revise its LLW regulation to address this point. Until then, the staff should amend the technical position to reflect more directly the attention that leaching resistance merits.

- Testing requirements should be representative of conditions likely to be encountered in an SLB site.

- Testing requirements of waste form radiation resistance may not be sufficiently conservative when considering the potential for hydrogen generation in closed spaces.

- Testing requirements of aged waste forms is insufficient.

- Ongoing revisions to 10 CFR Part 20 (10 CFR 20.311 at the time) need comparison to the technical position to ensure compatibility.

- Newly developed criteria for compressive strength of acceptable cementitious waste forms [500 pounds per square inch (psi)] lack a strong technical justification but were selected to preclude the use of unstable waste forms. The staff should recognize that the waste form may not retain the compressive strength that is initially called for in the guidance for its required life. Long-term degradation of compressive strength to lower levels, but not less than the approximately 60 psi required for other waste forms, may be acceptable.

Source Term and Other Low-Level Waste Considerations (March 31, 1993). The ACNW convened a working group to obtain better information on the inventory of radionuclides in commercial LLW going into disposal facilities. At the time, the Commission was considering amendments to its regulations to improve the quality and uniformity of information on LLW transfers between generators and operators. The Committee noted that one of the guiding criterion in the ongoing development of the Uniform Low-Level Waste Manifest System[96] was to provide data deemed essential to LLW disposal facility performance assessments. In its 1993 letter, the Committee observed that the staff should confirm that the manifest data collected could be used through the full range of disposal environments likely to be found consistent with the site-specific

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[96]"Appendix G to Part 20 - "Requirements for Transfers of Low-Level Radioactive Waste Intended for Disposal at Licensed Land Disposal Facilities and Manifests."

data requirements imposed by the 10 CFR Part 61 regulation for estimating the release and transport of radionuclides from disposal facilities. The letter highlighted many other source term observations/considerations proposed or discussed by the working group participants. See NRC (1992c, 1995b) for more background on this issue.

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APPENDIX A
MANAGEMENT OF GOVERNMENT-GENERATED LOW-LEVEL RADIOACTIVE WASTE BY THE U.S. DEPARTMENT OF ENERGY

A-1 INTRODUCTION[1]

Under the Atomic Energy Act of 1954, as amended (AEA), the U.S. Department of Energy (DOE or the Department) is responsible for research and development (R&D) and defense production involving nuclear materials, as well as for managing those materials in a manner that protects public health and safety. Before DOE, this responsibility fell first to the U.S. Army Corps of Engineers in the 1940s and then to the Atomic Energy Commission (AEC) during the Cold War era.

Nearly every step in the production of materials and parts for nuclear weapons generates radioactive waste and other radioactive byproduct materials. Government-generated radioactive wastes have been produced at more than 50 current and former DOE R&D and weapons production facilities located around the United States. Some of these wastes include spent nuclear fuel (SNF), liquid high-level radioactive waste (HLW), low-level radioactive waste (LLW), and transuranic (TRU) radioactive waste. Cleanup activities associated with the decommissioning of certain DOE facilities has also produced LLW in the form of contaminated soil, debris from dismantled facilities, and other scrap materials. A significant proportion of Government-generated LLW is contaminated with chemically-hazardous materials and are considered chemically mixed LLW (MLLW). A 1999 National Research Council report (p. 25) estimated that between 50 and 80 percent of DOE LLW is chemically mixed.

[1]As with commercial LLW, much has been written about the management of Government-owned LLW. This appendix briefly reviews how DOE manages those wastes. For additional information, see *http://web.em.doe.gov/doclistb.html.*

The AEA assigned the initial responsibility for the management of Government-generated radioactive wastes to the AEC. Successor agencies, including the Energy Research and Development Administration and most recently DOE, have continued this stewardship. Consistent with the AEA, the U.S. Nuclear Regulatory Commission (NRC) does not regulate Government-generated radioactive wastes; DOE (and its predecessor agencies) self-regulate these wastes. However, the AEA does require that DOE keep radionuclide emissions from its facilities as low as reasonably achievable (ALARA). The Department is also required to meet the U.S. Environmental Protection Agency (EPA) radionuclide airborne emission standards called for in the Clean Air Act of 1977, as amended. Congressional passage of the Federal Facility Compliance Act of 1992 (FFCA) subjected DOE radioactive mixed waste management activities to additional Federal regulation. See Table A-1.

A-2 LLW MANAGEMENT

Like the NRC, DOE (1999, p. IV-1) defines LLW by identifying what it is not. Specifically, DOE defines LLW in the following manner:

> " radioactive waste that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, byproduct material (as defined in section 11e.(2) of the *Atomic Energy Act of 1954*, as amended), or naturally occurring radioactive material...."

Initially, the AEC operated the only LLW disposal facilities for both commercial and Government wastes. Government wastes were disposed of on site, at the point of generation, or

Table A-1 Legal Authorities for the Management and Disposal of DOE LLW

Statute	Responsibility	Guidance / Regulations
Atomic Energy Act of 1954, as amended	Authorizes DOE to self-regulate the management of its radioactive wastes.	DOE Order 435.1 and Manual 435.1-1 (for LLW)
Clean Air Act of 1977, as amended (CAA)	EPA adds radionuclides to the list of hazardous air pollutants under the CAA.	40 CFR Part 61
Federal Facility Compliance Act of 1992 (FFCA)	Requires Federal agencies to comply with same environmental regulations as non-Federal agencies. Authorizes EPA to enforce RCRA regulations at DOE facilities for the chemically hazardous constituents of its radioactive wastes.	Public Law 102–386
Resource Conservation Recovery Act of 1976 (RCRA)	Authorizes EPA to control wastes that are dangerous or potentially harmful to human health or the environment. Subtitle C of the RCRA regulations establishes a "cradle to grave" system for controlling hazardous waste from the time it is generated to when it is ultimately disposed. States can be authorized to implement their own RCRA programs in place of those of the EPA.	40 CFR Parts 260 through 279
The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)	Authorizes Federal agencies to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. Includes requirements for both short- and long-term actions to permanently and significantly reduce the dangers associated with releases or threats of releases of hazardous substances. The act requires that cleanup remedies be permanent and, to the extent practicable, cost effective. EPA administers these requirements through its Superfund Program.*	Chapter 103 of U.S. Code Title 42

* CERCLA disposal facilities do not require RCRA permits.

off site, at other AEC locations. When commercial disposal facilities began to operate, the AEC shipped some of its wastes to those facilities in an attempt to encourage and sustain their development (DOE, 2000; p. 1-2).

Following shutdowns of and disposal restrictions at commercial sites in 1979, the Department issued a policy statement directing all field offices to cease using those facilities and to begin using sites within the greater DOE complex. However, only 6 of the 20 major DOE waste generators had some type of waste disposal capability (U.S. General Accounting Office - GAO, 2000, pp. 8–9). Any site within the greater DOE complex unable to dispose of its wastes was to negotiate with other field offices for offsite disposal or was to request access to a commercial facility.[2]

To provide a comprehensive decisionmaking framework for managing its wastes and meeting its regulatory responsibilities, DOE prepared programmatic, as well as site-specific, environmental impact statements as required by the National Environmental Policy Act of 1969 (NEPA). As part of the NEPA process, DOE analyzed four different waste types - HLW, LLW, TRU waste, and MLLW - and reviewed

[2]GAO (2000) describes this process.

alternatives disposal options for each waste type. This analysis also included preparing an inventory of Government-owned LLW (Goyette, 1995). Two DOE reports (1997b and 1998b) discuss these NEPA decisions. The Department subsequently designated Hanford, Washington, and the Nevada Test Site as regional disposal sites for both LLW and MLLW because these sites had the greatest flexibility in terms of the types and amounts of wastes that they could receive. To the extent practicable, the Idaho National Engineering and Environmental Laboratory, the Los Alamos National Laboratory (New Mexico), the Oak Ridge Reservation (Tennessee), and the Savannah River Site (South Carolina) would continue to dispose of their own LLW.

In 1993, DOE resumed the use of commercial facilities for the disposal of some of its LLW and MLLW. The Department permits the use of commercial disposal facilities when the use of existing DOE facilities is not practical or when a situation-specific cost-benefit analysis favors non-DOE site disposal. See Guevara (2001). The NRC, or comparable Agreement State programs, regulates DOE LLW disposed of at commercial LLW sites.

The National Safety Council (2002) describes DOE's current LLW management program.

A-2.1 DOE Waste Management Orders

The Department employs management and operating contractors to run its facilities, and DOE field managers oversee daily operations. To ensure consistent management of its facilities, the Department has relied on "orders" (i.e., policies, guidelines, and minimum requirements) supplemented by implementing "manuals," which provide specific implementation instructions The orders do not have the same legal authority as Government regulations published in the *Code of Federal Regulations*; rather, the orders represent the key contractual requirements each facility operator must meet for the generation, treatment, storage, and disposal of wastes at a particular site (to the extent the service contract specifies particular orders). DOE headquarters staff prepares the orders, which are then implemented by Department field managers who directly oversee the various contractors and subcontractors that manage those sites. The first DOE radioactive waste management order was issued in August 1982. See DOE (1982). Since then, the Department has released several revisions, the most recent in July 1999. Order 435.1, "Radioactive Waste Management" (DOE, 1999a), covers all Government-owned HLW, LLW, TRU waste, and the radioactive components of MLLW.

The Department automatically reviews its orders every 2 years to determine whether they should be continued, revised, or cancelled [DOE, 1998, [page 42013 of Volume 63 of the *Federal Register* published August 6, 1998 (63 FR 42013)]. Consistent with this policy, DOE had begun to review Order 5820.2A (DOE, 1988) in the early 1990s. Order 5820.2A was not unlike Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (10 CFR Part 61) in that it shared many of the same performance objectives and other prescriptive requirements found in the NRC LLW regulation. See International Technology Corporation (1991) for a comparison of these two sets of requirements. Following an independent review of DOE's LLW management programs, the Defense Nuclear Facilities Safety Board (DNFSB or the Board)[3] issued Recommendation 94-2 (also known as DNFSB 94-2), "Conformance with Safety Standards at DOE Low-Level Nuclear Waste and Disposal Sites" to the Secretary of Energy (DNFSB, 1994). They recommended that the Department undertake a comprehensive,

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[3]Congress established the DNFSB as an independent Federal agency in 1988. Pursuant to the AEA, the Board provides safety oversight of the DOE nuclear weapons complex.

complex-wide review of its LLW management programs in response to questions concerning the performance of various DOE field offices in complying with the then applicable Order 5820.2A. For example, the DNFSB noted that none of the site-specific performance assessments stipulated in that order had been completed and approved. The Board observed that such performance assessments were necessary to evaluate compliance with standing DOE orders and other applicable statutes.

As a first step in responding to DNFSB 94-2, the Secretary of Energy directed the Department to prepare a program management plan for its LLW and MLLW programs; DOE issued that plan in March 1997 (DOE, 1997a). The Department also committed to continued reliance on an oversight and peer review panel.[4] Following the DNFSB review, DOE also issued a proposed revision to Order 5820.2A (Order 435.1) in August 1998 (DOE, 1998). In July 1999, after a public comment period, DOE issued its revised radioactive waste management order and the associated implementing manual.[5]

A-2.2 DOE Order 435.1

When revising Order 5820.2A, DOE emphasized performance-based requirements. The current Order 435.1 contains three basic performance objectives (i.e., radiological dose criteria) that are intended to protect the public, workers, and the environment (DOE, 1999a, p. 3). Using performance assessment methods, this order calls for compliance with those dose criteria for a time period of 1000 years following disposal facility closure (DOE, 1999b, p. IV-11). In addition, implementing Manual 435.1-1 specifies a separate human intruder scenario analysis (Op cit., p. IV-12. Also see Table A-2).[6] By relying on a performance-based directive, DOE field managers have the flexibility to determine the quality and quantity of waste that can be disposed of at a particular site, design a particular disposal facility given a particular site and waste inventory, and in consideration of the aforementioned, to decide whether an extended caretaker period (with institutional controls) will be necessary beyond 100 years.[7]"

As the NRC did when developing the 10 CFR Part 61 dose requirements (see Section 7.4 of this report), DOE also relied on the recommendations of the International Commission on Radiological Protection (ICRP) in Publication 26 (1977) to develop its radiological compliance (performance) criteria. DOE radiation protection exposure standards for the public, Order 5400.5, "Radiation Protection of the Public and the Environment" (DOE, 1990), incorporates these criteria. The DOE standards permit a total exposure of 100 millirem per year (mrem/yr) in the form of an effective dose equivalent to an individual member of the public from all sources.

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[4]The order also included a provision for the use of an oversight and peer review panel to evaluate those performance assessments to ensure consistency throughout the Department. An LLW Disposal Facility Federal Review Group (LFRG) superseded this panel and assumed expanded responsibilities. See LFRG (2000).

[5]The DOE Record of Decision for the public comments received on Order 435.1 can be found at *http://web.em.doe.gov/em30/pubsum16.html.*

[6]DOE (1996) provides guidance on the Department's expectations for the conduct of LLW performance assessments. This guidance is also supported by a "critical assumptions" document (Alm, 1997) that describes the Department's views on key performance assessment policy issues.

In addition, Appendix D to this report discusses the NRC staff's views on the LLW performance assessment process, as well as certain key performance assessment policy issues.

[7]DOE (1999b, p. IV-12) currently assumes a 100-year caretaker period for its LLW and MLLW sites. However, the radiological and chemical risks posed by some DOE disposal sites may extend well beyond 100 years and thus may entail longer-term stewardship by the Department. See National Research Council (2000).

Table A-2 Dose Guidelines for DOE LLW Disposal Facilities

Receptor (Point of Compliance)	Pathway	Compliance Criterion	Reference
Public	All Pathways	not to exceed 100 mrem/yr whole-body exposure from all sources [a]	DOE (1990, p. II-1)
		not to exceed 25 mrem/yr whole-body exposure from disposal unit [b]	DOE (1999b, p. IV-10)
	Air Pathway	not to exceed 10 mrem/yr whole-body exposure from disposal unit [b]	DOE (1999b, p. IV-10[c])
	Ingestion Pathway [d]	not to exceed 4 mrem/yr	DOE (1990, p. II-5)
Hypothetical Inadvertent Intruder	All Pathways	100 mrem/yr from chronic exposure [b]	DOE (1999b, p. IV-12)
		500 mrem/yr from single acute exposure [b]	DOE (1999b, p. IV-12)
Worker [e]	All Pathways	5 rem/yr whole-body exposure from all sources	DOE (1993)
Environment	Air Pathway	for radon gas (radon-220 and radon-222), average flux at surface of disposal unit not to exceed an average of 20 $pCi/m^2/s$ [b]	DOE (1999b, pp. IV-10 – IV-1l)

a. Required for the *composite analysis* DOE (1999b, p. IV-12).
b. Required for the *performance assessment* DOE (1999b, pp. IV-12 – IV-13).
c. See also EPA (1979).
d. Drinking water.
e. Defined by DOE as a "general employee."

Of this total, only 25 mrem/yr can result from exposure from the operation of an LLW disposal facility. Furthermore, only 10 mrem/yr can result from inhalation exposures, and exposures from drinking water provided by a public supply at the site are limited to 4 mrem/yr. In addition, all radiological exposures must be consistent with the NRC's ALARA principle. Permissible levels of radioactivity would, therefore, depend on the ability of the disposal system (i.e., the site and design) to contain the radioactive material.

A-2.3 DOE Manual 435.1-1

DOE retained many of the more prescriptive requirements previously found in Order 5820.2A, but relocated them in the revision of the implementing manual for Order 435.1. Chapter IV of the updated manual (DOE M 435.1-1) specifically addresses the management of LLW (DOE, 1999b). Similar to the NRC 10 CFR Part 61 regulation, DOE Manual 435.1-1 emphasizes an integrated-systems approach to LLW management and disposal, including consideration of site selection, facility design and operation, waste acceptance and waste form requirements, and disposal facility closure. To ensure effective management of DOE wastes, the manual focuses on the front end of the LLW life cycle by including provisions for waste generation planning (i.e, waste minimization), waste characterization, transportation requirements, and waste certification. These requirements ensure that the site, including appropriate design and minimum waste acceptance criteria, can operate safely and comply with all applicable regulations, both during facility operation and after site closure.

In addition to a site-specific performance assessment, DOE must conduct a site-specific composite radiological analysis that accounts for any sources of radioactive material not disposed of in the LLW disposal facility, particularly those materials that are left in situ and may contribute to a projected dose to hypothetical receptors. Similar to the performance assessment for the LLW disposal facility itself, the DOE dose standards permit a total exposure of 100 mrem/yr in the form of an effective dose equivalent to an individual member of the public from all sources. However, if the performance assessment results exceed 30 mrem/yr, DOE requires additional analysis or efforts to reduce and/or control the potential for exposure.

A-2.4 Other DOE LLW Management Requirements

This appendix summarizes the DOE approach to managing LLW, which is complicated by the need to comply with other Federal regulations (see Table A-1). For example, as previously noted, a significant proportion of LLW is contaminated with materials that are also chemically hazardous. Before 1987, the Department took the position that EPA's RCRA regulations did not apply to chemically mixed radioactive wastes (GAO, 1994, p. 18). However, since 1987, DOE has managed the hazardous components of MLLW in a manner consistent with those regulations. Depending on the RCRA-listed substance, a National Research Council report (1999, p. 25) estimates that this could affect between 50 and 80 percent of DOE MLLW. Before disposal, these wastes will require some level of pretreatment (i.e., stabilization) to meet the applicable disposal standards. See National Research Council (1999). Challenging the Department's ability to manage its LLW and MLLW inventory is the need to decide on an optimal (pretreated) waste form that satisfies both RCRA disposal requirements and standing DOE waste management orders. See GAO (2000a, 2000b, 2001, 2005).

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APPENDIX B
REGULATORY EVOLUTION OF THE LOW-LEVEL RADIOACTIVE WASTE DEFINITION

B-1 INTRODUCTION

Radioactive waste results initially from the mining of naturally-occurring uraniferous mineral ores (Finch et al., 1973) to recover uranium oxides, which are then used to make nuclear materials. Each subsequent step in the nuclear fuel cycle[1] produces other types and quantities of radioactive waste (e.g., Finch, 1997, p. 5). Neither the Atomic Energy Acts (AEA) of 1946 or 1954, which authorized the production and use of radioactive materials for defense and civilian purposes, made reference to radioactive waste or to radioactive waste disposal.

Kocher (1990) previously summarized the historical development of the regulatory definitions of low-level radioactive waste (LLW) and other classes of radioactive waste. That review indicates that the definition of " LLW" has varied over the years. The current definition of LLW is exclusionary. That is to say it is defined by what it is not. Before the promulgation of the U.S. Nuclear Regulatory Commission (NRC or the Commission) LLW disposal regulations found at Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61), the term LLW was had a precise definition. In general, LLW was defined as that portion of the solid radioactive waste stream that did not fit the prevailing definition of high-level radioactive waste (HLW) or intermediate-level radioactive waste and had concentrations of transuranic (TRU) elements less than 100 nanocuries per gram (nCi/g). For its part, the U.S. Department of Energy - DOE (1995, p. 48) has previously characterized the current definition as a "catchall" term for everything that is not HLW, TRU waste, spent nuclear fuel (SNF), or uranium mill tailings.

The NRC considers LLW with activity comparable to that of SNF to be greater-than-Class C (GTCC) radioactive waste. As noted in Appendix A to this report, DOE is responsible for managing such wastes.

B-2 DISCUSSION

The use of nuclear power reactors to produce fissionable materials for defense purposes beginning in the 1940s and to generate electricity for the civilian sector beginning in the 1950s has been the primary source of radioactive wastes. The regulatory systems that define these materials were developed initially to ensure worker safety during the handling and storage of the wastes (National Council on Radiation Protection - NCRP, 2002; p. 175). Two waste forms were of concern. Liquid (aqueous) radioactive wastes and solid radioactive wastes.

B-2.1 Initial Radioactive Waste Definitions [2]

The earliest administrative description (definition) of radioactive waste was based on the operational

[1]Generally defined to include uranium mining and milling, uranium hexafluoride (UF_6) conversion, enrichment, uranium fuel fabrication, spent fuel reprocessing and recycling, and waste storage/disposal. See DOE (1979, p. 2-1).

[2]Researchers have proposed alternative radioactive waste classification systems for the United States. See Kocher and Croff (1987, 1988), Smith and Cohen (1989), and LeMone and Jacobi (1993). The NCRP (2002) summarized these proposals, along with the details of its recommended waste classification system. These researchers' proposals are similar to the International Atomic Energy Agency's (1994) recommendations in that they all recognized the association of waste classes with available disposal systems, most included a class of exempt waste or equivalent, and all suggested quantitative boundaries between the various waste classes.

aspects of handling and storing the liquid wastes generated in reprocessing SNF for defense purposes and the subsequent reprocessing of such wastes. The definitions were introduced by the Atomic Energy Commission (AEC), in the 1950s, prior to the current legislative and regulatory framework of definitions that is now in place. Liquid radioactive wastes contained varying concentrations of radionuclides, primarily short-lived fission products, and long-lived alpha-emitting transuranium radionuclides. At the time, Kocher (1990, p. 59) noted the AEC's primary concern was worker protection from radiation exposures during waste-handling operations rather than protection of the public.

To permit their safe handling and storage, the AEC introduced a three-tier classification system essentially based on the concentration of fission products. In decreasing order of hazard, this system classified wastes as HLW, medium or intermediate-level wastes, and LLW (Lennemann, 1973, p. 361). Liquid HLW generated during reprocessing contained the highest concentrations of radionuclides (i.e., strontium-90 and cesium-137), and other long-lived radionuclides (i.e., plutonium-139 and americium-241). These government-generated wastes were managed by confinement in underground tanks. Medium or intermediate-level liquid wastes contained lower concentrations of radionuclides than HLW and could be discharged into seepage basins that permitted delayed release of the radionuclides into the environment. LLW contained the lowest concentrations of radionuclides from reprocessing and could be released to holding ponds and lagoons or discharged directly to surface waters. There were no uniform concentration limits for each AEC liquid radioactive waste class. Instead, each AEC site developed its own concentration limits based on the prevailing site-specific management practices. At the Hanford nuclear reservation, for example, the following limits were used to classify liquid wastes from SNF reprocessing 100 to 200 days after removal from the reactor (Beard and Godfrey, 1976; p. 124):

- HLW - *total activity concentrations greater than 100 Ci/m^3*
- Intermediate-level - *total activity concentrations ranging from 5×10^{-5} to 100 Ci/m^3*
- LLW - *total activity concentrations less than 5×10^{-5} Ci/m^3*

As noted previously in this report, the AEC assumed responsibility for the disposal of civilian-produced solid radioactive waste in the early 1960s until commercial disposal facilities for those wastes could be developed. For statistical purposes, the AEC defined three different categories of solid radioactive waste that would be acceptable for shallow-land disposal based on the following arbitrary concentration limits (Lennemann, 1967, p. 264):

- High - *total activity concentrations greater than 35,300 Ci/m^3*
- Intermediate - *total activity concentrations ranging from 353 to 35,300 Ci/m^3*
- Low - *total activity concentrations less than 353 Ci/m^3*

It is important to note that the differing AEC descriptions of liquid and solid radioactive wastes resulted primarily from differences in radionuclide compositions (i.e., the source of the waste - government versus private sector) and the operational requirements for safe handling at waste generating sites rather than with the potential long-term impacts of disposal on public health and the environment (NCRP, 2002, pp. 173–174).

In the late 1960s, a fourth solid waste category, TRU, came into existence. Soon after, the AEC established a policy (Hollingsworth, 1970) that solid radioactive waste with concentrations of alpha-emitting radionuclides greater than 10 nCi/g was not acceptable for shallow land burial (SLB), but required storage and/or burial in a retrievable manner.[3]

B-2.2 Definition of HLW

HLW was the first constituent of commercial radioactive waste streams to receive a regulatory definition. In the early days of the commercial nuclear power program, it was assumed that SNF would be reprocessed and the residual uranium and plutonium would be recycled as fuel (Metlay, 1981, p. 204). In 1970, the AEC published the "Policy Relating to the Siting of Fuel Reprocessing Plants and Related Waste Management Facilities," as Appendix F to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," that defined HLW in the following manner:

> "those aqueous wastes resulting from the operation of a first-cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels...." [published in the *Federal Register* on November 14, 1970, Volume 35, page 17533 (35 FR 17533)]

Given this policy, HLW became whatever material was left after fuel reprocessing and recycling. Consequently, HLW was defined as the liquid wastes resulting from a particular source (i.e., reprocessing) rather than the waste's constituents or radiological properties.

[3]The AEC selected a threshold of 10 nCi/g because, at the time, it represented the highest concentration of radium in the Earth's crust (AEC, 1974).

For both economic and political reasons, commercial reprocessing was never undertaken extensively in the United States. At the time the AEC published Appendix F to 10 CFR Part 50, very little domestic commercial reprocessing or recycling capacity existed.[4] In addition, the evolving regulatory climate raised questions about the economic competitiveness of the process compared with the cost of using fresh nuclear fuel. See Metlay (1981, p. 205) and OTA (1985, pp. 67–68).[5] Concerns about the potential proliferation of weapons-grade nuclear material produced during reprocessing led the Ford Administration to impose a moratorium in 1976 (Op cit., p. 87).[6] To ease the burden of

[4]ERDA operated two large-scale plants in Savannah River, Georgia, and Hanford, Washington, for reprocessing Government-owned nuclear fuel. Nuclear Fuel Services, Inc. (NFS) operated the only commercial nuclear fuel reprocessing plant in the United States. Located in West Valley, New York, the facility operated under an AEC license. Allied General Nuclear Services and General Electric Corporation built two additional commercial reprocessing facilities in Barnwell, South Carolina, and Morris, Illinois, respectively (Zebroski and Levenson, 1976, pp. 119–120).

[5]During its 6 years of operation (1966–72), the West Valley facility reprocessed 160 metric tons of commercial SNF and 480 metric tons of fuel from defense production reactors at Hanford. The facility closed-down in 1972 for modifications to increase its processing capacity, reduce occupational exposures, and reduce radioactive effluents. However, between 1972 and 1976, major changes occurred in the AEC regulatory requirements related to the operation of nuclear facilities. After reviewing the new regulatory requirements, NFS determined that future reprocessing activities would not be profitable and withdrew from the business without removing any of the in-process liquid radioactive wastes. In 1980, Congress passed the West Valley Demonstration Project (WVDP) Act (Public Law 96-368) directing DOE to solidify the onsite liquid radioactive wastes for ultimate disposal in a geologic repository. See DOE (2003).

[6]In March 2006, DOE announced its intent to prepare an environmental impact statement (EIS) pursuant to the National Environmental Protection Act (NEPA) and the Global Nuclear Energy Partnership to evaluate the potential environmental impacts of new management technologies, including proliferation-resistant technologies

utilities that, because of the moratorium, had already been storing increasing quantities of SNF on site, the Carter Administration established a policy whereby the Federal Government would take title to, and possession of, commercial SNF for ultimate disposal in a geologic repository. Shortly before this policy was established, the Energy Research and Development Administration (ERDA) initiated the National Waste Terminal Storage Program to survey locations as candidate sites for the disposal of commercial SNF and other HLW (Interagency Review Group on Nuclear Waste Management, 1979).

In 1974, Congress established the first legislative definition of HLW when it passed the Marine Protection, Research and Sanctuaries Act (Public Law 95-532). In Section 3(j) of that act ("Definitions"), Congress adopted the earlier 1970 AEC definition of HLW. See 35 FR 17533.

Title II of the Energy Reorganization Act of 1974 transferred to the NRC the regulatory authority initially assigned to the AEC. Section 202 of the act gave the NRC specific authority to regulate certain ERDA waste management facilities, including those used primarily for the receipt or storage of HLW from commercially licensed activities (e.g., reactors, reprocessing plants). Although not defined in the act, the prevailing AEC Appendix F definition was understood (U.S. General Accounting Office, 1977, p. 23).

In 1982, Congress passed the Nuclear Waste Policy Act (NWPA) (Public Law 97-425), which provided further clarification regarding the definition of HLW. This clarification included specific legislative reference for the first time to SNF. Section 2.(12) of the act defines the term "HLW" in the following manner:

> "(A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and
>
> (B) other highly radioactive material that the [Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation..."

The law also established the current DOE waste management program directing the Department to site, design, build, and operate a Federal repository for the geologic disposal of SNF and other HLW (DOE, 1985a, 1985b). The act also specified that any commercial liquid HLW to be disposed of in a geologic repository must be solidified for permanent disposal.[7]

Shortly before the passage of the NWPA, the U.S. Environmental Protection Agency (EPA) proposed generally applicable radiation standards for the management and disposal of SNF, HLW, and TRU wastes at 40 CFR Part 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes" (EPA, 1982). In its proposed environmental radiation standards, EPA defined HLW at 40 CFR 191.02(b) in the following manner:

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for the reprocessing and recycling of SNF. See DOE (2006a, 2006b).

[7] In May 1981, DOE prepared a programmatic EIS on the selection of a preferred strategy for the disposal of commercially generated radioactive wastes. Without defining them, DOE indicated its intent to dispose of commercially generated HLW and TRU waste in a mined geologic repository (DOE, 1981).

"any of the following that contain radionuclides in concentrations greater than those in Table 1 [Appendix[8]]: (1) liquid wastes resulting from the operations of the first-cycle solvent extraction system, or equivalent, in a facility for reprocessing spent nuclear fuels; (2) the concentrated wastes from subsequent extraction cycles, or equivalent; (3) solids into which such liquid wastes have been converted; or (4) spent nuclear fuel if disposed of without reprocessing...." (47 FR 58204)

However, in its final standards EPA (1985) decided to adopt the NWPA legislative definition of HLW (50 FR 38075).

The NWPA also directed the NRC to promulgate generic geologic disposal regulations for HLW. In 10 CFR 60.2, "Definitions," of those regulations - 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories" - the Commission expanded the definition of HLW in 1983 to include irradiated fuel assemblies from commercial nuclear power plants and dry solid materials [9] in the following manner:

"(1) irradiated reactor fuel, (2) liquid wastes resulting from operations of a first-cycle solvent extraction system, or equivalent, and concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for fuel reprocessing, and (3) solids into which such liquid wastes have been converted..." (48 FR 28218)

In a 1987 advance notice of proposed rulemaking (ANPR), the NRC proposed to modify the existing regulatory definition of HLW to apply the term "high-level radioactive waste" to materials in quantities and concentrations exceeding numerical values that would be stated explicitly in a table (52 FR 5992). The Commission proposed to classify radioactive wastes as either high level or non-high level. The NRC would classify those wastes that could not be disposed of safely in a hypothetical "intermediate" disposal facility as HLW. Following a review of public comments on the ANPR, the Commission adopted an alternative strategy. In 1988, the NRC published its proposed amendments to 10 CFR Part 61 recommending that GTCC LLW be disposed of in a separate facility licensed under 10 CFR Part 60 (NRC, 1988).

B-2.3 Definition of TRU Waste

TRU wastes are the byproducts of fuel assembly and weapons fabrication and reprocessing operations. These wastes contain isotopes higher than uranium, which is number 92 on the Periodic Table of Elements and characteristically have long half-lives and high radiotoxicity. The AEC (Hollingsworth, 1970, p. 2) originally

[8] EPA proposed a concentration table (Table 1) of certain long-lived radionuclides to be used to identify HLW (47 FR 58206). In adopting the NWPA definition of HLW, EPA set aside its earlier Table 1 recommendation.

[9] This later addition to the definition reflected the production of dry solid materials during the limited SNF reprocessing demonstration at the WVDP facility. See DOE (2003). The legislation governing the WVDP defined HLW to include the following:

"liquid wastes produced directly in reprocessing, dry solid material derived from such liquid waste, and such other material as the NRC designates as high-level waste for the purposes of protecting public health and safety...."

defined this waste stream as solid waste with:

> " known or detectable contamination of transuranium radionuclides..."[10]

Congress gave TRU waste its first legislative definition in the Low-Level Waste Policy Act of 1980 (LLWPA) (Public Law 96-425), but the definition was later rescinded in 1985 when the act was amended. Before 1982, AEC Manual Chapter 0511 defined TRU waste as having greater than 10 nCi/g of the long-lived alpha-emitting transuranium radionuclides (Hollingsworth, 1970). This manual chapter also stated that solid wastes contaminated with certain alpha-emitting radionuclides to greater than 10 nCi/g should be stored in such a way as to allow the packages to be readily retrieved (Op cit., p. 2). As this directive was implemented, the 10 nCi/g limit gradually was construed as a concentration limit that defined the distinction between LLW (material appropriate for SLB) and other radioactive material destined for disposal in a more secure mode (e.g., deep geologic disposal). See Steindler et al. (1982, p. 590). In 1982, Federal agencies concurred with a recommendation to increase the existing transuranium radionuclide concentration limit from 10 to 100 nCi/g (Op cit.) for this class of wastes.

In its 1982 draft environmental radiation standards, EPA proposed a new definition for TRU waste (47 FR 58204). In 1985, EPA finalized its standards and defined TRU waste at 40 CFR 191.02, "Definitions," in the following manner:

> "wastes containing more than 100 nanocuries of alpha-emitting transuranium isotopes, with half-lives greater than twenty years, per gram of waste, except for (1) high-level radioactive wastes; (2) waste that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this Part; or (3) waste that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61...." (50 FR 38084)

In 1980, Congress authorized DOE to build a full-scale research and development (R&D) facility to test the safe management and disposal of defense-generated TRU wastes at Los Medaños near Carlsbad, New Mexico (DOE, 1990b).[11]

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[10]At the time, the AEC noted that the detection limit of equipment used for the routine checking of plutonium-containing waste packages was approximately 500 milligrams per cubic foot for a 5-cubic-foot package (DOE, 2003).

[11]Investigation of the Los Medaños site initially took place as part of the National Waste Terminal Storage Program (National Research Council, 1970). Geologically, the Los Medaños site is a bedded, Permian-age evaporite (salt) deposit of the Salado Formation within the Delaware Basin. The goal of this program was to locate a suitable geologic setting for the disposal of radioactive waste (Bredehoeft et al., 1978; National Research Council, 1978).

With the passage of the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164), Congress authorized DOE to build the WIPP R&D facility. This law also exempted WIPP from independent NRC oversight and regulation. Following several years of scientific evaluation and testing, Congress directed DOE, in the Waste Isolation Pilot Plant Land Withdrawal Act (Public Law 102-579), to seek an EPA "certification" to allow waste emplacement operations to commence. The EPA certification criteria (1996, 61 FR 5224) required that the WIPP site and design meet the Subpart B and C performance objectives of the EPA radiation standards at 10 CFR Part 191. In May 1998, EPA reviewed the Department's compliance certification application (DOE, 1996) and found that the WIPP could comply with the pertinent radiation standards (EPA, 1998). For the most part, Sandia National Laboratories (SNL) conducted these performance assessments. Rechard (1995) describes the

This R&D facility was later renamed the Waste Isolation Pilot Plant (WIPP). In association with the WIPP development program, DOE prepared a number of NEPA-related documents. All of these documents (DOE, 1980, 1989b, 1990a) used the prevailing definition of TRU waste at the time of their respective publication (Steindler et al., 1982).[12]

NRC considers TRU waste as a higher activity form of LLW (i.e., GTCC waste) subject to disposal in an HLW repository or some other disposal facility approved and licensed by the NRC. See Section 7.5.1 of this report. Kocher (1990, p. 67) notes that the NRC has not developed a regulatory definition of TRU waste because only small quantities are produced in the civilian sector and EPA currently regulates its disposal.

general approach used by the SNL for conducting those assessments, and Helton et al. (1999) provides a summary of the results.

Public Law 96-164 also required that DOE comply with any other applicable environmental standards in operating WIPP. The majority of the TRU wastes are chemically mixed wastes subject to EPA regulation under the authority of the Resource Conservation and Recovery Act (RCRA) as well as other EPA land disposal prohibitions. To dispose of these wastes, DOE submitted a RCRA no migration variance petition to EPA (DOE, 1989a). However, Congress amended Public Law 102-579 in 1995 to exempt the WIPP site from RCRA requirements. See also National Research Council (1996) and DOE (2000).

[12]TRU waste can be further classified according to the radiation dose rate at the package surface. Contact-handled TRU waste emits primarily alpha radiation. It has radiation dose rates at the package surface dose rate below 200 millirem per hour (mrem/hr) and therefore generally can be handled without extensive shielding. Remotely handled TRU waste contains isotopes that emit alpha, beta, and gamma radiation. Remotely handled TRU TRU waste has a package surface dose rate exceeding 200 mrem/hr and therefore requires heavy shielding for safe handling and storage. See DOE (1990a, Vol. 1, pp. 2-8 – 2-9).

B-2.4 Definition of LLW

As discussed earlier in Section B-2.1, LLW was originally defined by the AEC to include any radioactive waste with concentrations of radionuclides less than those in HLW or intermediate-level radioactive waste, taking into account worker protection needs at the waste generating sites. Subsequent regulatory and legislative actions related to the (re)definition of HLW and TRU waste changed the current regulatory definition of LLW to one of exclusion (National Research Council, 2006, p. 120). Although the NRC has the statutory authority to define LLW, it has not done so. Rather, the category of "LLW" had been defined by default - in other words, it was defined by what it was not - and it includes the definition of wastes not otherwise classified (52 FR 5994). In the NWPA, as amended, LLW is defined as radioactive waste that is not "high-level radioactive waste, transuranic waste, spent fuel, or uranium or thorium mill tailings...."

Furthermore, the Low-Level Waste Policy Amendments Act of 1985 (LLWPAA) (Public Law 99-240), does not define LLW. Paragraph (2)(A) of the "Definitions" section of the LLWPAA notes that LLW is not HLW, SNF, or byproduct material; Paragraph (2)(B) of this same section simply says that "the Nuclear Regulatory Commission, consistent with existing law, classifies...low-level waste...."

Reorganization Plan No. 3 of 1970 (The White House, 1970) granted EPA its standard-setting authority at Section 2(a)(6) to establish "generally applicable environmental standards for the protection of the general environment from radioactive material" (35 FR 15624). EPA was to develop environmental standards for all commercial radioactive waste streams. As discussed in the previous section, EPA promulgated radiation standards for SNF, HLW, and TRU wastes at 40 CFR Part 191. In August 1983, EPA published an ANPR (48 FR 39563) announcing its plans to establish general environmental radiation protection standards for LLW. In 1987, the Agency forwarded those proposed standards to the U.S. Office of Management and Budget (OMB) for approval. The Agency also published a draft EIS (EPA, 1988) in connection with the development of those standards.

In describing the proposed LLW standards, Gruhlke et al. (1989, p. 273) noted that EPA proposed to define LLW in the following manner:

> "radioactive waste that was not (1) spent fuel, high-level radioactive waste, or transuranic waste, as previously defined in 40 CFR Part 191, (2) or uranium or thorium mill tailings subject to 40 CFR Part 192[13], or (3) or NARM[14] as defined in 40 CFR [Part] 764...."

However, the proposed EPA LLW standards did not clear the OMB review process and were never published in the *Federal Register* for public comment. The proposed rule encountered significant interagency opposition stemming from concerns about the ground-water provisions of the proposed standard. See Pelletier (1991). In 1994, EPA circulated a second "pre-proposal" LLW standard for interagency review and comment. One (new) major concern identified was that the proposed EPA LLW standard would delay the development of new disposal sites taking place at the time (EPA, 2000b, p. 21). As a compromise, in 1995, EPA drafted a proposal to limit the applicability of its new standard to Federally-operated (DOE) LLW disposal sites, but this proposal was never issued.

As noted in Section 7.4.2 of this report, the EPA LLW standards and criteria were not available at the time the NRC was developing its LLW regulatory framework. Rather than delay the development of its disposal regulations, the NRC staff decided to postulate a reasonable set of "study guidelines" that could be used as surrogates for the EPA standard. At the time, no nationally accepted set of guidelines defined the level of safety (protection) that disposal facilities should provide to safeguard the public from the effects of ionizing radiation. Consequently, the staff decided to review the literature and consider the recommendations of national and international standard-setting organizations to identify surrogate dose guidelines for the scoping analyses and the subsequent proposed and final rules.[15]

As a result of the EIS scoping and rulemaking processes, the staff developed a three-tier LLW classification system in which wastes with increasing concentrations of radionuclides are subject to increasingly more stringent disposal requirements (NRC, 1982). As defined in 10 CFR 61.55 ("Waste Classification"), the three classes of LLW acceptable for SLB are Class A, B, and C, with Class C waste having the highest concentration of radionuclides. Class designations are tied to certain minimum requirements and stability requirements[16] and to

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[13]The EPA health and environmental protection standards for uranium and thorium mill tailings (EPA, 1983b). Consistent with the NWPA and LLWPAA, mill tailings are not considered a form of LLW.

[14]Naturally occurring or accelerator-produced radioactive materials.

[15]See Appendix N, "Analysis of Existing Recommendations, Regulations, and Guides," to Volume 4 of NUREG-0782, "Draft Environmental Impact Statement on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Wastes" (NRC, 1981b).

[16]Title 10, Section 61.56(a), of the *Code of Federal Regulations* provides the minimum requirements that all waste forms must meet to be acceptable for near-surface disposal. In addition to these minimum requirements, certain wastes (i.e., Class B and C wastes and Class A

specifications for maximum allowable concentrations of certain radionuclides in each class.

Class A LLW primarily includes lightly contaminated paper, cloth, and plastics. These wastes must be segregated from other LLW during disposal because of their potential for physical degradation over time, leading to ground subsidence in disposal cells. The isotope concentrations in this class of wastes are not to exceed the values listed in the regulation. Class B LLW by definition must meet more rigorous physical stability requirements than Class A wastes. This waste class is also permitted higher isotope concentrations. The physical form and characteristics of Class B LLW must also the meet minimum and stability requirements of the regulation at 10 CFR 61.51(a) and 10 CFR 61.51(b), respectively. Class C LLW is generally considered intruder waste.[17] This higher-activity, longer-lived LLW is generally suitable for SLB, but requires special design measures to protect against human intrusion after institutional controls have lapsed. The regulation requires that any Class C waste with concentrations of radionuclides that could cause exposures greater than 500 millirem (mrem) needs to be protected from intrusion by deeper burial and/or through the use of some type of engineered barrier. Wastes exceeding the Class C concentration limits are, by regulation at 10 CFR 61.55(a), generally not suitable for SLB.

10 CFR Part 61 thus does not define LLW. Rather, it represents a subclassification of a particular waste class developed primarily for the purposes of managing commercial LLW disposal in SLB facilities (NCRP, 2002, p. 190). Although it did issue an ANPR, EPA was never successful in promulgating LLW radiation protection standards (GAO, 1993) and, as a consequence, 10 CFR Part 61 has become the prevailing regulation defining commercial LLW.

In a 1987 ANPR, the NRC proposed to modify the existing definition of HLW to apply the term "high-level radioactive waste" to radioactive materials in quantities and concentrations exceeding numerical values that would be stated explicitly in a table (52 FR 5995). The NRC intended this rulemaking to address LLW with radionuclide concentrations above the existing Class C limits of 10 CFR Part 61 because wastes classified as "LLW" were not subject to any upper regulatory limit and some LLW may have concentrations approaching those of HLW (52 FR 5994). Following a review of public comments on the ANPR, the Commission adopted an alternative strategy. In 1988, the NRC published its proposed amendments to 10 CFR Part 61 recommending that GTCC waste be disposed of in a separate facility licensed under 10 CFR Part 60, the NRC's generic regulations for the disposal of HLW (53 FR 17709). In 1989, the Commission finalized the so-called GTCC disposal amendments (54 FR

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waste that is to be co-disposed with Class B and C waste) must be structurally stabilized and meet the requirements of 10 CFR 61.56(b). Stability is defined in terms of the ability to keep dimensions and form under disposal conditions. Stability can be provided by the waste form (e.g., activated metals), by processing the waste to an acceptable form (e.g., cement solidification), by placing the waste in a high-integrity container, or by the disposal unit itself (e.g., vault disposal).

[17] In the draft proposed regulation (NRC, 1981a), only Class C LLW was identified as "intruder waste" (46 FR 38084). Although this designation was not repeated in the final regulation, some practitioners continue to use this terminology. As noted earlier in Section 7.3 of this report, the reader is reminded that the Commission's regulations at Part 61 are mainly intended to provide protection to inadvertent human intruders to SLBs to all three classes of LLW. To protect the public, the 10 CFR 61.55 waste classification system was developed to specify the limits of concentrations of radionuclides acceptable for SLB, under assumed human intrusion scenarios, in each LLW waste class. Therefore, Class A and B LLW should also be recognized as "intruder waste."

22578).[18]

In summary, the LLW definition is no longer related to requirements for safe waste handling and storage or permanent disposal because its management was no longer restricted to containing wastes with low concentrations of radionuclides. LLW now includes wastes with high concentrations of relatively short-lived beta/gamma-emitting radionuclides (i.e., cobalt-60) as well as high-concentrations of long-lived fission or activation products (i.e., technetium-99, thorium-232). As a consequence, LLW can now include wastes destined for different types of disposal facilities. See NCRP (2002, p. 175).

The net effect of the legislative and regulatory actions described above is that no statutory lower limit (either upper or lower) exists for the level of radioactivity required to declare material as "LLW" (National Research Council, 2006, p. 120). This is an important point because a suite of "lower" activity radioactive wastes that occur in concentrations greater than background but less than Class A materials is not subject to comprehensive regulation. These low-activity radioactive wastes (LAW) include technologically concentrated radioactive substances derived from natural materials containing radioactive elements, slightly contaminated materials from decontaminated nuclear facilities, and short-lived, manmade radioactive materials produced by atomic particle accelerators.

B-2.5 Low-Activity Radioactive Wastes

Naturally occurring radioactive materials (NORM) can be found in rocks, soils, water, and air. Although these materials occur widely in nature, their radiation levels are barely detectable, with concentrations on the order of only a few tens per parts per million (Clark et al., 1965). See Table B-1. Primordial radioactivity, that is, radioactivity associated with the geologic formation of the earth, consists primarily of the natural elements uranium-238, thorium-232, and potassium-40 and their decay products. Together with cosmic radiation (Kohman and Saito, 1954; Suess, 1958), these two radiation sources contribute about 82 percent of all ionizing radiation an average individual receives annually in the United States, which is estimated to be about 360 millirem per year (mrem/yr) from both natural and manmade sources (NCRP, 1987, p. 55).[19] Unless materials containing these elements are extracted from the earth, segregated, and processed into concentrated forms, they are not generally considered a threat to public health and safety.

In 1975, researchers recognized that certain human activities can result in the unintentional yet anomalous concentration of natural radioactivity to levels greater than those found in the environment. Gesell and Prichard (1975) cited examples of these anomalous concentrations, including radiation emissions from coal-fired power plants, radon in harvested natural gas, radium in manufactured fertilizer and processed drinking water, and enhanced cosmic ray exposure in high-altitude aircraft. Because of the potential for significant occupational or population exposures above natural background levels, Gesell and Prichard recommended that a new category of radiation exposure be recognized — technologically enhanced natural radiation (TENR) - to permit evaluation of the potential health risk to LAW (although not defined as such at the time). Since then, this category has received other designations in the literature (NORM, NARM, and technologically-enhanced naturally occurring radioactive materials or

[18] In 2001, NRC issued new site-specific disposal regulations for the proposed Yucca Mountain repository at 10 CFR Part 63, as required by the Energy Policy Act of 1992 (Public Law 102-486). These regulations would also require GTCC waste be disposed of in a separate facility licensed under 10 CFR Part 63. See 66 FR 55791-55792.

[19] The actual dose for any individual may vary widely.

Table B-1 Primordial (Terrestrial) and Cosmic Radiation Sources

Source	Activity / Concentration / Exposure		Reference(s)
Primordial—U-238 series, Th-232 series, and K-40			
igneous (rock type)	U-238 Th-232 K-40	1.33 pCi/g 1.31 pCi/g 21.6 pCi/g	Shapiro (1990, p. 367)*
limestone (rock type)	U-238 Th-232 K-40	0.43 pCi/g 0.14 pCi/g 2.25 pCi/g	Shapiro (1990, p. 367)*
granite (rock type)	U-238 Th-232 K-40	>3.0 pCi/g >3.9 pCi/g >29 pCi/g	Shapiro (1990, p. 367)*
sandstone (rock type)	U-238 Th-232 K-40	0.40 pCi/g 0.65 pCi/g 9.1 pCi/g	Shapiro (1990, p. 367)*
shale (rock type)	U-238 Th-232 K-40	0.40 pCi/g 1.09 pCi/g 22.5 pCi/g	Shapiro (1990, p. 367)*
ultramafic rocks and eclogites	U-238 Th-232 K-40	0.0004–0.21 ppm 0.001–0.43 ppm 12–527 ppm	Clark et al. (1965, p. 528)*
soil	Ra-222 Ra-226	0.2–4.2 pCi/g	Gundersen and Wanty (1991); Nazaroff (1992)
water	U-238 Ra-226 Th-232	0.01–10 μg/L <1pCi/L 0.01–1 μg/L	Hem (1985, pp. 148–149)*
Cosmic—C-14, H-3, Be-7, Na-22			
ground level		10 μrem/hr	Gesell and Prichard (1975, p. 365)*
subsonic air travel		1000 μrem/hr	Gesell and Prichard (1975, p. 365)*

* Citing others.

TENORM) as well as the addition of other material streams. See Table B-2.

In general, most of the material streams listed in Table B-2 do not represent a significant hazard to the public and the environment. However, some of the low-activity materials (and wastes) can contain long-lived radionuclides at levels well above background and thus may represent a chronic and even an acute hazard to the public and the environment. See National Research Council, 1990). For this reason, and given the potential volume of waste material of concern – estimated to be on the order of 10^9 cubic feet (10^4 cubic meters) annually (EPA, 2000a, p. 2) – there is a question as to whether the Federal Government should take greater responsibility for the management of LAW.

Table B-2 Potential Sources of LAW

Source/Mode	Radionuclides	Concentration/ Exposure	Reference(s)
TENR / NORM			
Building Materials:			
red-mud brick	Ra-226	7.6 pCi/g	Austin (1988, p. 5) [a]
fly-ash brick	Ra-226	5.7 pCi/g	Austin (1988, p. 5) [a]
tuffaceous brick	Ra-226	6.5 pCi/g	Austin (1988, p. 5) [a]
concrete	Ra-226	35 pCi/g	Austin (1988, p. 5) [a]
phosphogypsum	Ra-226	17 pCi/g	Austin (1988, p. 5) [a]
Coal			
lignite coal	Ra-226	1 pCi/g	Gesell and Prichard (1975, p. 362) [a]
fly ash	Ra-226	3.9 pCi/g	Egidi and Hull (1999, p. 26) [a]
coal ash	several	0.1–7.0 pCi/g	Egidi and Hull (1999, p. 40) [a]
Geothermal Energy Production	Ra-226	132 pCi/g	Egidi and Hull (1999, p. 53) [a]
Mine Tailings:			
alumina ores	Ra-226	7.4 pCi/g	Austin (1988, p. 5) [a]
phosphate ores	Ra-226	3–50 pCi/g	Austin (1988, p. 5) [a]
titanium ores	Ra-226	12–15 pCi/g	Austin (1988, p. 5) [a]
zirconium ores	Ra-226	13 pCi/g	Austin (1988, p. 5) [a]
Municipal Waste Water Treatment			
dry sludge	several	0–44 pCi/g	Interagency Steering Committee on Radiation Standards (2003, p. 17)
incinerated ash	several	0–91 pCi/g	Interagency Steering Committee on Radiation Standards (2003, p. 17)
Oil and Natural Gas Production	several	120–360 pCi/g	Egidi and Hull (1999, p. 43) [a]
Phosphate Fertilizer	U-238, Ra-226	400 ppm	Gesell and Prichard (1975, p. 364)
NARM / TENORM			
Accelerator-Produced Radioisotopes	several	variable	Baum et al. (2002); Nuclear Energy Agency (1998)
URANIUM AND THORIUM MILL TAILINGS			
Mineral Ore wastes	Th-232, U-238, U-235, Ra-226	+20 pCi/g	Austin (1988, p. 5) [a]

Source/Mode	Radionuclides	Concentration/ Exposure	Reference(s)
DECOMMISSIONING OF NRC-LICENSED FACILITIES			
Slightly Contaminated or Clearance Radioactive Materials [b]	mostly short-lived fission and activation products ($t_{½} = 10^1$ yrs)	variable	National Research Council (2002[a], 2003)

a. Citing others.
b. Surface contamination, activated metals of high activity, and penetrating radiation.

As noted earlier in this paper, NRC Agreement States had initially recommended that the AEC (or its successor) undertake the overall responsibility for regulating LAW (Lacker, 1974). The NRC's earlier *de minimis* position and the Below Regulatory Concern Policy Statements described in Section 3.5 of this report addressed the question of an appropriate waste/nonwaste threshold. The agency recognized that, at some minimum level of exposure, certain radioactive materials no longer pose a risk to public health and safety and therefore could be unregulated. EPA attempted to develop radiation standards for the management of LAW in the 1980s in parallel with the development of its LLW radiation standards (EPA, 1983a). Focusing on NARM, EPA proposed a new regulation at 40 CFR Part 764, "Environmental Standards for Management, Storage, and Land Disposal of Naturally Occurring and Accelerator-Produced Radioactive Waste: Draft Proposed Rule," to require the disposal of NARM in concentrations exceeding 2 nCi/g in a 10 CFR Part 61 LLW disposal facility. Wastes with concentrations below 2 nCi/g would not be considered LLW. See Gruhlke et al. (1989, p. 275). EPA (1988, p. 1-2) cited the Toxic Substances Control Act of 1976 (Public Law 94-469) as the proper legal authority for the proposed NARM regulations and noted that the AEA excludes the regulation of NARM radionuclides. Neither the proposed LLW nor the proposed NARM regulations cleared the Federal interagency review process.

In 2003, EPA published an ANPR that discussed alternatives for the disposal of chemical wastes containing low concentrations of radioactive material (68 FR 65119). One alternative cited in the ANPR is the use of RCRA Subtitle-C disposal technology for such wastes.

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APPENDIX C
STRUCTURE OF 10 CFR PART 61

Title 10, "Energy," Chapter I, of the *Code of Federal Regulations* documents the U.S. Nuclear Regulatory Commission (NRC) regulations. Chapter I is divided into Parts 1 through 199. Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61) describes how the NRC will license construction authorization, operation, and permanent closure of a low-level radioactive waste disposal facility. The table below lists the key regulatory features of 10 CFR Part 61. A full-text version of the 10 CFR Part 61 regulation is available on the NRC Web site at http:*//www.nrc.gov/reading-rm/doc-collections/cfr/ part061/.*

Subpart	Subpart Title	Section	Section Title
A	General Provisions	61.1	Purpose and scope
		61.2	Definitions
		61.3	License required
		61.4	Communications
		61.5	Interpretations
		61.6	Exemptions
		61.7	Concepts
		61.8	Information collection requirements: OMB approval
		61.9	Employee protection
		61.9a	Completeness and accuracy of information
		61.9b	Deliberate misconduct
B	Licenses	61.10	Content of application
		61.11	General information
		61.12	Specific technical information
		61.13	Technical analyses
		61.14	Institutional information
		61.15	Financial information
		61.16	Other information
		61.20	Filing and distribution of application
		61.21	Elimination of repetition
		61.22	Updating of application
		61.23	Standards for issuance of a license
		61.24	Conditions of licenses

Subpart	Subpart Title	Section	Section Title
B	Licenses (continued)	61.25	Changes
		61.26	Amendment of license
		61.27	Application for renewal or closure
		61.28	Contents of application for closure
		61.29	Post-closure observation and maintenance
		61.30	Transfer of license
		61.31	Termination of license
C	Performance Objectives	61.40	General requirement
		61.41	Protection of the general population from releases of radioactivity
		61.42	Protection of individuals from inadvertent intrusion
		61.43	Protection of individuals during operations
		61.44	Stability of the disposal site after closure
D	Technical Requirements for Land Disposal Facilities	61.50	Disposal site suitability requirements for land disposal
		61.51	Disposal site design for land disposal
		61.52	Land disposal facility operation and disposal site closure
		61.53	Environmental monitoring
		61.54	Alternative requirements for design and operations
		61.55	Waste classification
		61.56	Waste characteristics
		61.57	Labeling
		61.58	Alternative requirements for waste classification and characteristics
		61.59	Institutional requirements
E	Financial Assurances	61.61	Applicant qualifications and assurances
		61.62	Funding for disposal site closure and stabilization
		61.63	Financial assurances for institutional controls
F	Participation by State Governments and Indian Tribes	61.70	Scope
		61.71	State and Tribal government consultation
		61.72	Filing of proposals for State and Tribal participation
		61.73	Commission approval of proposals

Subpart	Subpart Title	Section	Section Title
G	Records, Reports, Tests, and Inspections	61.80	Maintenance of records, reports, and transfers
		61.81	Tests at land disposal facilities
		61.82	Commission inspections of land disposal facilities
		61.83	Violations
		61.84	Criminal penalties

APPENDIX D
A SUMMARY OF NUREG-1573: A PERFORMANCE ASSESSMENT METHODOLOGY FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES

Before the October 2000 publication of NUREG-1573, "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities — Recommendations of NRC's Performance Assessment Working Group," existing U.S. Nuclear Regulatory Commission (NRC or the staff) guidance documents did not specifically deal with the evaluation of low-level radioactive waste (LLW) disposal facility designs and performance against the performance objectives detailed in Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the *Code of Federal Regulations* (10 CFR Part 61). These guidance documents contained general information and did not address many specific implementation issues and acceptable approaches for resolving them. Moreover, existing guidance did not explicitly address the relationship between the overall 10 CFR Part 61 data and design requirements and specific LLW performance assessment needs. Previously, NRC guidance considered site characterization, facility design, and performance modeling as separate activities.

To clarify these and other 10 CFR Part 61 implementation issues, the staff developed detailed information and recommendations for potential applicants, specifically related to the performance objective at 10 CFR 61.41 concerned with the radiological protection of the general public. The NRC published detailed information and recommendations in NUREG-1573 (NRC, 2000).

The following section summarizes the information and recommendations found in NUREG-1573.

D-1 INTRODUCTION

A disposal facility for the containment and isolation of radioactive wastes is a complex system. It is generally expected to consist of multiple barriers,[1] with each barrier contributing to the overall performance of the system by providing some degree of redundancy to ensure the containment and isolation of wastes. Because the future performance of a disposal facility must be estimated for many hundreds or thousands of years into the future, analysts use predictive mathematical models to evaluate the long-term performance of each barrier class, as well as the overall system. These models are usually implemented through computer codes that rely on numerical methods.

Consensus exists within the international community that disposal facility developers and regulators will rely on state-of-the-art performance assessment analyses to evaluate the safety of these facilities before they are licensed and operational.[2] Because of the inherent

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[1]Depending on the hazard posed by the waste, two barrier classes, engineered and natural, may be used, and several individual barriers may exist within each barrier class.

[2]Risk assessment, safety assessment, performance assessment, probabilistic risk assessment (PRA), and similar concepts are terms of art among practitioners; thus, no widely agreed-to set of definitions exists. A Nuclear Energy Agency (1999) report reviews the meaning and intent of some of the more widely used terms in the performance assessment lexicon. Moreover, the concept of risk assessment itself may be subject to some variability in interpretation. See Fjeld and Compton (1998, p. 4166).

Nevertheless, the NRC has been very active in developing PRA technology and applying it to nuclear facility safety.

uncertainties in the models and data used to evaluate the performance of disposal system components, performance assessments often are conducted probabilistically, in an iterative fashion. This approach allows the analyst to quantitatively evaluate the impacts of parameter and model uncertainty on the results, which are used to determine compliance with the performance objectives. Performance assessment may thus be defined as the process of quantitatively evaluating the capability of a disposal facility to contain and isolate radioactive wastes. See Campbell and Cranwell (1988). Deterministic approaches to performance assessment, when single parameter values and models are analyzed, do not explicitly evaluate uncertainties but assume the use of "conservative" parameters and models to bound the results. NRC staff evaluations of performance assessments, whether deterministic or probabilistic, take into account uncertainty and variability.

D-2 BACKGROUND

In conjunction with the development of 10 CFR Part 61 and after its promulgation in 1982, the NRC staff began to undertake a variety of performance-assessment-related projects that addressed LLW disposal, primarily in shallow land burial (SLB) facilities. The staff initiated projects in areas such as waste package performance and leaching, hydrogeological and hydrogeochemical characterization and modeling, and cover performance. The staff also began to investigate alternatives to SLB disposal and developed guidance for the licensing of other types of LLW disposal facilities (e.g., above-ground vaults, below-ground vaults, earth-mounded concrete bunkers, mined cavities, and augured holes). See NRC (1991, 1994a).

As early as 1987, the staff recognized that some type of assessment methodology would need to be "acquired or developed" for estimating the performance of 10 CFR Part 61 LLW disposal facilities [page 5996 of Volume 52 of the *Federal Register,* published February 27, 1987 (NRC, 1987, 52 FR 5996)]. To provide focus and integration of the overall LLW program and to address the need for a more integrated approach to evaluating the performance of any LLW disposal facility design, the NRC staff formulated an overall LLW performance assessment strategy in 1987. This strategy (Starmer et al., 1988) recommended an overall systems approach for assessing the performance of LLW disposal facilities. The strategy also recommended a modular approach for quantifying the potential release and transport of radionuclides through significant environmental pathways. The NRC later contracted with Sandia National Laboratories (SNL) to develop an LLW performance assessment methodology (PAM) based on this strategy with additional approaches for quantitatively evaluating uncertainties in the overall system model.[3] The NRC published the PAM in a five-volume series as NUREG/CR-5453, "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology — Assessment of Relative Significance of Migration and Exposure Pathways," issued in December 1989. Concurrently, the staff published an LLW Research Program Plan (O'Donnell and Lambert, 1989), which presented its strategy for

For example, see PRA Working Group (1994). In 1995, the Commission issued a policy statement that encouraged the use of PRA methods as a complement to the deterministic approach in its nuclear regulatory activities (NRC, 1994b). See Appendix F to this report. Over the last few decades, the NRC staff has expanded its use of PRAs in the area of waste management. Because waste management systems are passive, the NRC had to adapt PRA methods and analyses, which are now renamed performance assessments. See Eisenberg et al. (1999).

[3]The PAM, as later adopted by the staff, also provides specific recommendations on approaches for the following key performance assessment modules: source term, engineered barriers, ground-water flow and transport, and dose.

conducting research in the LLW area.

Shortly thereafter, the staff began developing an LLW performance assessment program plan (NRC, 1992), which had two primary goals. The first was to enhance the staff's capability to review and evaluate license applications within the 15 months specified by the Low-Level Radioactive Waste Policy Act, as amended. The second goal was to develop the in-house capability to prepare performance assessment guidance, should such guidance be necessary.[4] This plan responded to needs identified by both the Agreement States and the staff through interactions with prospective commercial disposal facility developers (i.e., applicants), review of U.S. Department of Energy (DOE) prototype license applications, and specific performance assessment issues raised by the States.

Consistent with its 1992 program plan, the staff and its technical assistance contractors enhanced the NRC's performance assessment expertise by conducting a variety of LLW modeling exercises and analyses.[5] The staff also initiated computer simulations of a "test case problem" for a hypothetical LLW disposal system. Allied performance assessment work conducted in other NRC waste management areas, such as high-level radioactive waste and decommissioning, also benefitted the staff's efforts to enhance its performance assessment expertise.

[4]The Commission's 1995 PRA Policy Statement served as another "driver" behind the development of the staff's LLW performance assessment program.

[5]An early LLW performance assessment analysis performed by the NRC staff was published in 1992 as part of a survey of Federal risk assessment efforts. See DOE et al. (1992, Appendix G). Dunkelman (1987) provides an extensive bibliography of NRC-sponsored technical assistance (including performance assessment-related activities) performed before work on NUREG-1573 commenced. The references cited in NUREG-1573 provide an update to the Dunkelman compilation, and this report (at Appendix E) updates that bibliography.

D-3 NUREG-1573

The efforts described above identified several areas in which additional LLW performance assessment guidance might be needed, as applied to the NRC LLW regulatory framework. For example, the staff found that existing NRC guidance documents - NUREG-1199, NUREG-1200, and NUREG-1300 - did not clearly delineate the relationship between the 10 CFR Part 61 data and design requirements and a detailed LLW performance assessment. The scopes of the three NUREGs were intended to provide guidance on demonstrating compliance with all Subpart C performance objectives, including the performance objective at 10 CFR 61.41, "Protection of the General Population from Releases of Radioactivity." Moreover, many of the performance assessment issues of concern came to light after the time the staff was conducting the 10 CFR Part 61 environmental impact statement (EIS) scoping process or, even later, during the LLW rulemaking effort. The areas of staff concern (NRC, 1990, p. 1-13) included the following:

- achieving a common understanding of the minimum elements of an LLW performance assessment process

- defining the relationship between site characterization and performance assessment data collection

- modeling infiltration rate estimation, source-term release behavior, and concrete and engineered barrier degradation

- modeling radionuclide transport in the environment

- making decisions related to performance assessment models and the validation and verification of computer models

- making decisions related to the use of generic versus site-specific data in performance assessment models

- developing approaches to uncertainty and sensitivity analyses

To address these concerns and to develop consensus approaches, the staff created an LLW performance assessment methodology guidance document, NUREG-1573. This and earlier NUREG guidance documents focused on developing recommendations for acceptable approaches and methods that could be used to demonstrate compliance with the 10 CFR Part 61 performance objectives.

In January 1994, the staff prepared a preliminary draft of the NUREG and distributed it for comment to all LLW-sited and host Agreement States, the Advisory Committee on Nuclear Waste (ACNW), DOE, the U.S. Environmental Protection Agency (EPA), and the U.S. Geological Survey. After that initial review process, the NRC staff sponsored a 2-day workshop, held at the NRC headquarters on November 16 and 17, 1994, to discuss the preliminary draft NUREG and an attendant LLW test case.[6] The staff also sponsored a half-day LLW performance assessment workshop in conjunction with the 16th Annual DOE/LLW Management Conference on December 13–15, 1994. The NRC subsequently modified NUREG-1573 to reflect information received during these interactions as well as specific direction from the Commission (NRC, 1996). The agency issued a revised draft for formal public comment on May 29, 1997 (62 FR 29164), as a branch technical position (BTP). Following a review of public comments, the staff clarified certain issues and issued the final NUREG in October 2000, but not as a BTP.[7]

D-3.1 Recommended Approaches, Attributes of Acceptable Approaches, and Staff Advice

In NUREG-1573, the staff proposed that applicants should develop and use a defensible methodology to demonstrate compliance of an LLW disposal facility design with the postclosure performance objective at 10 CFR 61.41. To help prospective applicants achieve this goal, the staff provided its views on three key performance

[6]The so-called "test case" analyzed the performance of a hypothetical LLW site and design as a means of evaluating whether the approaches recommended in NUREG-1573 were implementable. Using actual site data intended to be representative of a humid geographic environment and a hypothetical facility design and radionuclide inventory, the NRC staff tested a number of models that could be used in conducting an LLW performance assessment and gained experience with the use and limitations of LLW performance assessment modeling. Following its completion, the staff concluded that the test case demonstrated that the approaches recommended in NUREG-1573 could be implemented. However, the staff was unable to formally document the test case results because of resource constraints. The staff did present the results from the test case at a November 1994 2-day public workshop and there are transcripts of that meeting. Those transcripts are available for inspection and copying in NRC's Public Document Room. In addition to the meeting transcripts, preliminary results from the LLW test case have been described by Cady and Thaggard (1994), Campbell (1994), Campbell and McCartin (1994), and Krupka and Serne (1998).

[7]As a result of the public comment process, several commenters expressed concern that once the proposed guidance, particularly in the area of recommended policy approaches, was finalized, LLW disposal facility developers and other regulatory entities would view it as de facto NRC standards by virtue of its codification as a BTP. The staff noted (NRC, 2000, p. B-1) that the recommended technical and policy approaches in NUREG-1573 were not a substitute for NRC regulations and that compliance with those recommendations was never intended to be obligatory. However, to avoid the potential for future confusion in this area, the NRC published the final version of NUREG-1573 as a "technical report." Moreover, what were formerly staff positions or technical positions in the draft BTP were referred to as recommended approaches, attributes of an acceptable approach, staff advice, or words to that effect in the final NUREG.

assessment issues - (a) an acceptable LLW performance assessment approach (process), (b) the interpretation and implementation of five 10 CFR Part 61 regulatory requirements related to LLW performance assessment, and (c) ways to demonstrate implementation of the NRC PAM. See Table D-1.

D-3.1.1 Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41

In NUREG-1573, the staff recommended that prospective 10 CFR Part 61 license applicants develop a performance assessment process that systematically integrates site characterization data, facility design information, and predictive modeling results. The process is intended to build confidence in model estimates of LLW disposal site performance by providing a useful decisionmaking framework for evaluating and defending the appropriateness of data, assumptions, models, and codes used to demonstrate compliance with the postclosure performance objective at 10 CFR 61.41.

To achieve the degree of desired integration, NUREG-1573 recommended a nine-step performance assessment process, depicted in Figure D-1. The staff noted that the central attribute of the proposed process was that it be conducted iteratively, starting with a combination of generic and limited site-specific information in support of relatively simple conservative models and analyses and progressing as necessary to more realistic, site-specific, and detailed analyses to reduce uncertainty in assessing performance of (i.e, reaching decisions about) an LLW disposal facility (NRC, 2000a, pp. xi–x). Initial screening analyses identify the most important issues and data needs; as more site and design information is collected, modeling assumptions, conceptual models, and data needs are reevaluated. Site characterization and design bases are then revised to obtain data or modify the design as needed to reduce uncertainty and defend assessment results with respect to the postclosure performance objective at 10 CFR 61.41.

The performance assessment process outlined in NUREG-1573 was designed to be open and transparent so that all data, assumptions, and models would be well documented and understood. Moreover, this process intended that the rationale for any subsequent modification of those assumptions and models would also be documented and supported by an appropriate combination of site investigation and assessment data, valid technical reasoning, and sound professional judgment. In addition, the NUREG-1573 process incorporates a formal, probabilistically-based treatment of uncertainty as a basis for performance assessment decisionmaking, offers a technical basis for identifying the completion of site characterization, and enhances confidence that the disposal site complies with the postclosure performance objectives at 10 CFR 61.41.

Consistent with the Commission's views regarding the use of PRA, the staff also noted that the application of the performance assessment techniques to LLW disposal facility designs should be tempered according to the complexity of the disposal system, uncertainties surrounding system performance, and the estimated risks resulting from the types and kinds of wastes being disposed (NRC, 2000a, p. x).

D-3.1.2 Recommended Approaches to Technical Policy Issues

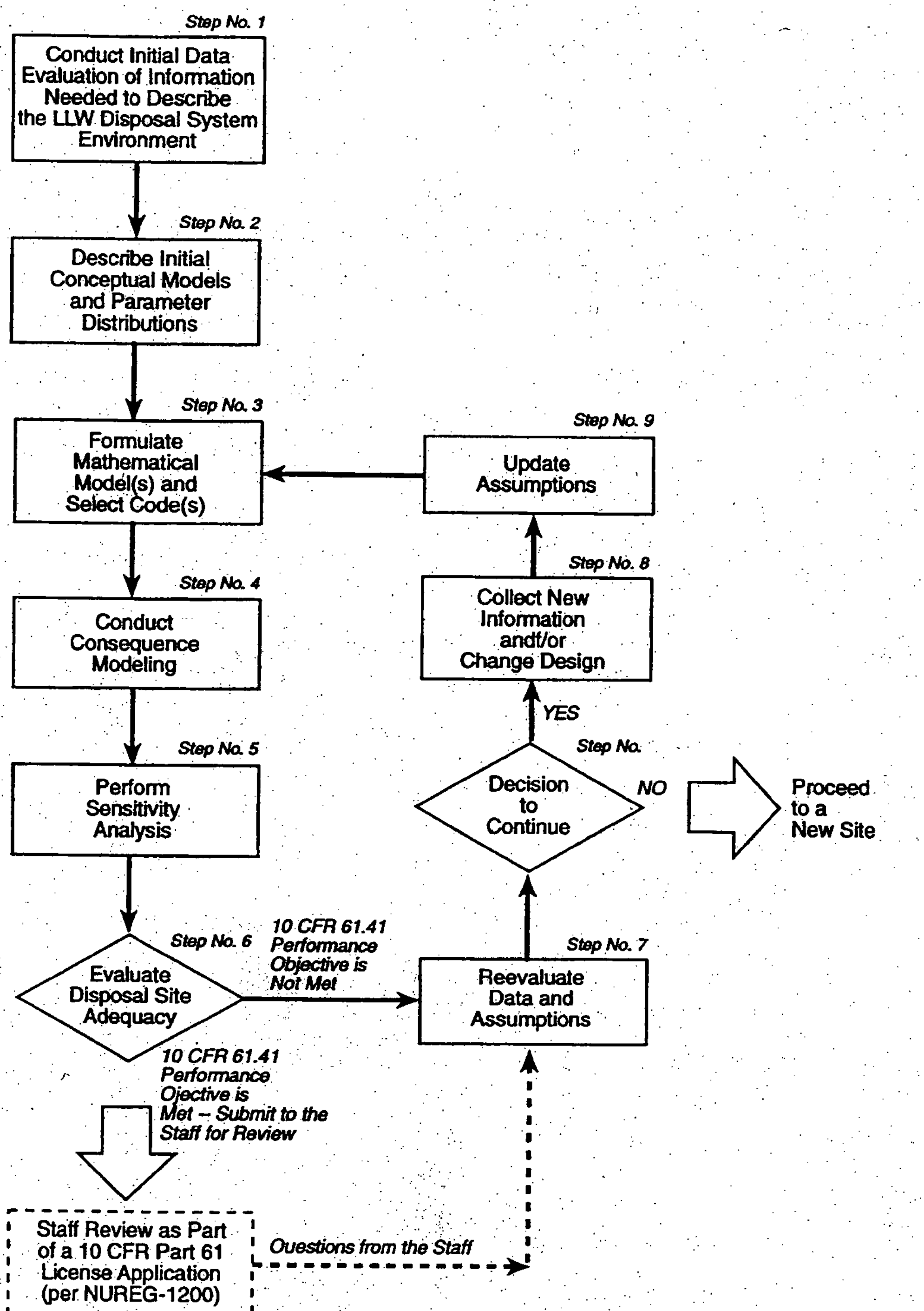
Technical policy issues represent fundamental questions pertaining to the interpretation and implementation of specific 10 CFR Part 61 performance objectives. In developing the performance assessment methodology outlined in NUREG-1573, the staff identified five areas in the regulation related to LLW performance assessment for which supplemental advice should be provided (NRC, 1996):

Table D-1 **Performance Assessment Technical Areas Covered by PAWG in NUREG-1573.**

Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41 (See Figure D-1 for details of this approach.)	
PAWG Views on Policy Issues Regarding 10 CFR Part 61 Performance Objectives and Technical Requirements (Also see Table D-1.)	
Role of the Site and Consideration of Site Conditions, Processes, and Events	Site Selection
	Site Conditions in Performance Assessment Models
Role of Engineered Barriers	
Timeframe for LLW Performance Assessment Analyses	
Treatment of Sensitivity and Uncertainty in LLW Performance Assessment	Role of Sensitivity and Uncertainty Analyses
	Recommended Approaches for Sensitivity and Uncertainty Analyses
	Compliance Determination
Role of LLW Performance Assessment during Operational and Closure Periods	
Recommended Approaches to LLW Performance Assessment Modeling Issues	
Uncertainty and Sensitivity Analysis	Sources of Uncertainty: Model Uncertainty and Parameter Uncertainty
	Issues
	Recommended Approaches to Treatment in Deterministic Analysis and Probabilistic Analysis Parametric Sensitivity Analysis
Infiltration	Key Considerations in the Analysis: Temporal Variation in Processes and Parameters and Spatial Variation in Parameters
	Recommended Approach: General Strategy and Approach
Engineered Barriers	Features and Dimensions of Engineered Barrier Systems
	Integration and Interaction of Materials
	Construction Quality and Testing
	Model Input

Recommended Approaches to LLW Performance Assessment Modeling Issues (continued)	
Engineered Barriers (continued)	Post-Construction Monitoring and Evaluation
	Use of Engineering Judgment
Source Term and Waste Type	Inventory of Radionuclides in LLW
	Screening Methods to Identify Significant Radionuclides
	Waste Form and Waste Type
	Waste Container
	Source Term Models
	Chemical Environment: Development of Site-Specific Parameters and Models (Radionuclide Distribution Coefficients and Geochemical Modeling of an LLW Disposal Facility)
	Gaseous Releases
Transport Media	Groundwater
	Surface Water (Below-Ground Disposal Facilities and Above-Ground Disposal Facilities)
	Air Transport (Screening Approach and Detailed Approaches)
Dose	Considerations: Pathway Identification and Modeling, Internal Dosimetry, and External Dosimetry
	Recommended Approaches: Pathway Identification, and Model Identification and Identification of Parameter Values
	Internal Dosimetry and External Dosimetry

Figure D-1 **Details of an "Example of an Acceptable Approach for Demonstrating Compliance with 10 CFR 61.41."** Taken from NRC (2000, p. 3-2).



(1) consideration of future site conditions, processes, and events
(2) performance of engineered barriers
(3) timeframe for an LLW performance assessment
(4) treatment of sensitivity and uncertainty in LLW performance assessments
(5) role of performance assessment during operational and closure periods

The earlier EIS scoping process and 10 CFR Part 61 rulemaking had not identified these areas (issues) because the generic LLW dose assessment methodology that had been developed in conjunction with those earlier activities (Adam and Rogers, 1978; Rogers, 1979; Rogers et al., 1979) was much simpler in many respects than the performance assessment process the staff now envisioned. The issues in question concern how LLW performance assessments are conducted and evaluated. Table D-2 presents the staff's views on these principal regulatory issues.

D-3.1.3 Recommended Analytical Approaches to Modeling Issues

The 1987 performance assessment strategy proposed by Starmer et al. advocated a modular approach to modeling LLW disposal systems, including dividing the disposal "system" into the following separate modeling areas:

- infiltration and unsaturated (vadose) zone flow
- engineered barrier performance (coupled with infiltration analysis to calculate the water flux into disposal units)
- radionuclide releases from waste forms and the bottoms of disposal units (container failure, leaching, and near-field transport)
- transport media such as groundwater, surface water, and air
- plant and animal uptake (food chain)
- dose to humans

The staff subsequently developed the PAM around this strategy. SNL developed the necessary methodology to undertake performance assessment analyses. This methodology assumes a generalized conceptual model of an LLW disposal site. Consistent with the 1987 performance assessment strategy, the NRC published the PAM in a five-volume series as NUREG/CR-5453,[8] which provided a basic set of models and computer codes for evaluating the following:

- infiltration behavior
- source term
- engineered barrier performance
- contaminant transport via groundwater,[9] surface water, and air
- dose to receptors

The modular PAM structure allows an LLW performance assessment to use a mix of both complex and simple models. Given the technical uncertainty of modeling LLW site performance and the diversity of sites and facility designs that various States and compacts may consider, flexibility to select appropriate subsystem models and codes is an important PAM attribute. Although the PAM can be implemented by separately analyzing each module, creating input to one subsystem model based on the results of another, NUREG-1573 outlines the potential benefits of automating subsystem model or code inputs and outputs with an overall system code, within the context of a broader performance assessment model. The staff noted that the benefits of an automated system code compared

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[8]See Shipers (1989); Shipers and Harlan (1989); and Kozak et al. (1989a, 1989b, 1990). Also see Chu et al. (1991).

[9]Including both the unsaturated and saturated zones.

Table D-2 NUREG-1573 Recommendations on Part 61 Regulatory Issues. Taken from NRC (2000, pp. xii–xv).

Regulatory Issue (NRC, 1996)	Staff NUREG-1573 Recommendation
Consideration of Future Site Conditions, Processes, and Events	Use realistic assumptions and ranges of parameters to effectively reflect the reference geologic setting for the site. To capture the variability in natural processes and events and dynamic site behavior, the range of siting assumptions and data should be sufficient to understand the long-term trends in natural phenomena acting on the site. NUREG-1573 emphasizes the need for a limit on the range of possible site conditions, processes, and events to be considered in an LLW performance assessment and for the elimination of unnecessary speculation in the assessment. In addition, consideration of societal changes would result in unnecessary speculation and therefore should not be included in an LLW performance assessment.
Performance of Engineered Barriers	An applicant should assign and justify the credit given to engineered barrier performance. Any period of time claimed for performance of an engineered barrier should be supported by suitable information and technical justification evaluated on a case-by-case basis. However, to limit unnecessary speculation as to their performance, the staff believes that materials typ ically used in engineered barriers can alternatively be assumed to have physically degraded 500 years after site closure. Thus, at 500 years and beyond, the engineered barriers can be assumed to function at performance levels considerably lower than their optimum level, but credit for structural stability and chemical buffering effects may be taken for longer periods of time. For timeframes longer than 500 years, it is unreasonable to assume that any physical engineered barrier, such as a cover or a reinforced concrete vault, can be designed to function long enough to influence the eventual release of long-lived radionuclides such as carbon-14 ($t_{½}$: 5300 years), technetium-99 ($t_{½}$: 213,000 years), and iodine-129($t_{½}$: 15,700,000 years), if they are present. However, credit for structural stability and chemical buffering effects may be taken for the long term provided that the applicant supplies suitable information and justification. But again, this would require case-by-case evaluations.
Timeframe for an LLW Performance Assessment	A timeframe for complying with the 10 CFR 61.41 postclosure performance objective is not specified in the regulation. To reduce unnecessary speculation regarding the performance assessment, a period of 10,000 years (i.e., the period of regulatory interest or concern) is sufficiently long to capture the peak dose from the more mobile long-lived radionuclides and to demonstrate the relationship of site suitability to the performance objective. The staff considered shorter periods, such as the 1000 years used in dose assessments for site decommissioning, to be generally inappropriate for assessments of LLW disposal facilities. Assessments beyond 10,000 years can be carried out to ensure that the disposal of certain types of waste does not result in markedly high doses to future generations or to evaluate waste disposal at arid sites with extremely long ground-water travel times. However, assessments of doses occurring after 10,000 years are not recommended for use as a basis for compliance with the performance objective.
Treatment of Sensitivity and Uncertainty in an LLW Performance Assessment	Formal sensitivity and uncertainty analyses should be conducted in support of performance assessment calculations. The staff considered two different approaches for representing system performance in the context of the postclosure performance objective. One approach provides a single bounding estimate of system performance supported by data and assumptions that clearly demonstrate the realistic nature of the analysis. The other approach provides a quantitative evaluation of uncertainty with regard to system performance represented by a distribution of potential outcomes. When compliance, as measured against 10 CFR 61.41, is based on a single (deterministic) estimate of performance, the applicant is relying on the demonstration of the conservative nature of the analysis, rather than a quantitative analysis of uncertainty. Therefore, if it is to be used as a performance measure, a single estimate of performance should be at or below the 10 CFR 61.41 performance objective. When a formal uncertainty analysis is performed and a distribution of potential outcomes for system performance is provided, to consider a facility in compliance, NUREG-1573 recommends that the peak of the mean dose as a function of time be less than the performance objective and a plot of the upper 95th percentile of doses at each discrete time be less than 100 mrem.

Regulatory Issue (NRC, 1996)	Staff NUREG-1573 Recommendation
Role of Performance Assessment during the Operational and Closure Periods	As required by 10 CFR Part 61, final LLW site closure plans must demonstrate the long-term safety of the facility and must include not only any additional geologic, hydrologic, or other disposal site data obtained during the operational period pertinent to the long-term containment of waste, but also the results of tests, experiments, or analyses pertaining to long-term containment of waste. This demonstration could include testing of assumptions about the performance of engineered aspects of the facility that are amenable to confirmation during operations. The site closure requirements suggest a need to keep performance assessments up to date as new information brings into question the bases of earlier assessments of LLW site safety.

to manually linked subsystem models may include (a) increased ability to proceed through successive iterations of the performance assessment process and perform uncertainty and sensitivity analyses, (b) a higher degree of quality assurance, (c) explicit recognition of assumptions that might be vague or inconsistently addressed, and (d) use of consistent parameters and values among subsystem models. The PAM furnishes a general methodology for conducting LLW performance assessments, whereas NUREG-1573 provides recommendations and advice (guidance) to address specific performance assessment issues, assuming the use of an analytical approach similar to the PAM.

After applying the PAM to the hypothetical LLW test case problem, the staff also recognized that the technical issues associated with the PAM had evolved and needed updating. NUREG-1573 provided the necessary updates. In the course of developing the PAM, the staff also identified and described, but did not address, a number of significant policy and technical issues. See Kozak et al. (1993, 1995). These issues were later referred to the Commission for consideration and reviewed within the context of the staff's NUREG-1573 recommendations. See NRC (1996).

D-3.2 Internal Dosimetry

NUREG-1573 noted that the 10 CFR Part 61 performance objective at 10 CFR 61.41 was based on the International Commission on Radiation Protection (ICRP) Publication 2 dose methodology (ICRP, 1959), but current health physics practices follow the dose methodology used in 10 CFR Part 20, "Standards for Protection Against Radiation," which is currently based on the ICRP Publication 30 methodology (ICRP, 1979). The staff noted that any 10 CFR Part 61 LLW license application would contain many other assessments of potential exposures (e.g., worker exposure, accident exposures, and operational releases) that would rely on the ICRP Publication 30 dose methodology. To ensure internal consistency of information in any license application, the staff recommended that the LLW performance assessment be consistent with the methodology approved by the NRC in 10 CFR Part 20, enabling comparison with the 10 CFR Part 61 performance objective. In this regard, the staff noted that the calculation of the total effective dose equivalent (TEDE), which sums the annual external dose and the committed effective dose equivalent, is acceptable for comparison with the performance objective. The NRC and other agencies have subsequently adopted updated dose methodologies. See Eckerman and Ryman (1993) and Eckerman et al. (1999).

As a matter of policy, NUREG-1573 also notes that the Commission considered 25 mrem/yr TEDE as the appropriate dose criterion to compare with the range of potential doses represented by the older criterion that included a whole body dose of 25 mrem/yr. See Footnote 1 in NRC (1999), at 64 FR 8644. The staff observed that potential applicants did not need to consider organ doses individually because the low value of the TEDE should ensure that no organ dose would exceed 50 mrem/yr.

D-3.3 Treatment of the Intruder Scenario

The performance goal at 10 CFR 61.42 is another Subpart C performance objective that could potentially bear on the overall performance objective at 10 CFR 61.41. This requirement establishes the need to "protec t inadvertent human intruders to the facility once disposal operations ceased and the facility decommissioned...."

In NUREG-1573, the staff noted that an LLW performance assessment was not expected to include separate dose analyses for human intruder scenarios (NRC, 2000b, p. 1-13). In making this determination, the staff noted that 10 CFR 61.13(b) already required that "analyses of the protection of individuals from inadvertent intrusion must include demonstration that there is reasonable assurance the waste classification and segregation requirements will be met and that adequate barriers to inadvertent intrusion will be provided...."[10]

D-3.4 Public Comments on NUREG-1573

The NRC published the draft NUREG-1573 for (formal) public comment on May 29, 1997 (62 FR 29164). The staff received 175 comments from 17 organizations and entities.[11] The staff reviewed the comments and concluded on balance, that the overall public reaction to the draft NUREG was favorable, with commenters stating general agreement with the proposed staff positions; that the document fulfills a need; that the document is well written; and that the document should be finalized. After reviewing the public comments, the staff determined that its original advice and recommendations were fundamentally sound and generally acceptable to stakeholders. Hence, no significant changes were necessary to address the comments received. The staff made only two major changes to the final version of NUREG-1573. First, the NUREG was no longer referred to as a BTP. Second, the staff modified its views on the treatment of uncertainties in an LLW performance assessment to better reflect the approach used in other NRC waste management programs. Appendix B to the final NUREG ("Disposition of Public Comments on May 29, 1997, Draft NUREG-1573, Including Updates to Technical References") includes the staff's response to each of the 175 public comments received and describes specific changes made by the staff to address each of the comments. Table D-3 summarizes these comments and the staff's general disposition of them.

In addition to the modifications described in Table D-3, other additions to the final NUREG in response to public comments included the following:

- an expanded glossary of technical terms used in the NUREG (as a new appendix)
- an expanded bibliography on engineered and natural barrier performance (as an

[10] The staff did acknowledge that separate intruder scenario analyses may be necessary when the projected waste spectra fundamentally differ from those considered in the technical analyses supporting any 10 CFR Part 61 draft EIS (DEIS). See NRC (1981). For example, an intruder analysis might be necessary if the waste forms proposed for disposal contain anomalous quantities and concentrations of certain long-lived radionuclides (e.g., uranium or thorium) so that the intruder cannot reasonably be protected by the waste classification and intruder barrier requirements of 10 CFR Part 61. To the extent that there may be a need for guidance on how to perform an intruder consequence analysis at an LLW disposal facility, NUREG-1573 referred disposal facility developers and other regulatory entities to the DEIS as the final EIS (NRC, 1982) did not include all of the information and references found in the earlier draft.

[11] Including NRC Agreement States (Illinois, Massachusetts, Nebraska, South Carolina, and Texas), non-Agreement States (New Jersey and Pennsylvania), DOE, EPA, the Nuclear Energy Institute, and other interested stakeholders.

Table D-3 **Summary of Staff Responses to Public Comments on NUREG-1573.** Taken from transcript of the 119th ACNW meeting, dated June 13, 2000.

Issue	Public Comment	Staff Response / NUREG-1573 Disposition [a]
10 CFR Part 61 Regulatory Issues [b]		
Timeframe for an LLW Performance Assessment	Varied opinions. Shorter, 500-year time-of-compliance more appropriate than staff recommendation. Alternatively, LLW performance assessment calculations should be to peak dose.	Original staff recommendation will generally include the period of time when LLW is the most hazardous. 10,000 years is consistent with other waste management regulations and supporting analyses. *No change made to final NUREG.*
Performance of Engineered Barriers	Assumed 500-year duration is arbitrary and without technical justification.	A 500-year timeframe is generally sufficient. Performance periods greater than 500 years are permitted, subject to justification by licensees. *No change made to final NUREG.*
Consideration of Future Site Conditions, Processes, and Events	Uncertainties in future human activities should be considered.	Consideration of future human activities is highly speculative. Use of a "reference biosphere" or "critical group concept" is consistent with other radioactive waste management applications. *No change made to final NUREG.*
Treatment of Sensitivity and Uncertainty in an LLW Performance Assessment	Varied opinions. Use of mean to provide best estimate of system performance not justified. Probabilistic analyses not politically supportable.	Proposed approach in NUREG is consistent with other NRC regulatory activities. *No change made to final NUREG.*
Other Comments		
Dose Methodology	NUREG inconsistent in recommending TEDE calculation while the regulation calls for the use of the older ICRP 2 methodology.	*Final version of NUREG modified to clarify inconsistency. In response, the staff noted that, as a matter of policy, the Commission considers 25 mrem/yr TEDE to be an appropriate dose limit to compare with the range of potential doses represented by the older whole body dose limits, consistent with Federal Guidance 11 (Eckerman et al., 1988).*
ALARA (as low as reasonably achievable) Considerations	NUREG should provide guidance on how to comply with ALARA requirements of 10 CFR 61.41.	*Final version of NUREG modified to include discussion on how to address ALARA requirements by looking at costs and benefits of various disposal facility designs.*
Institutional Controls	Institutional controls should be maintained at site as long as wastes remain hazardous.	100 years of caretaker oversight is generally considered conservative; institutional controls are likely, in practice, to remain in effect indefinitely. *No change made to final NUREG.*
Ground-Water Protection	Compliance with10 CFR 61.41 will not ensure that the U.S. Environmental Protection Agency's maximum concentration limits will be met.	Meeting MCLs is beyond the scope of the NUREG. Current regulations provide adequate protection. *No change made to final NUREG.*

Issue	Public Comment	Staff Response / NUREG-1573 Disposition [a]
Miscellaneous	Documentation of NRC LLW test case should be completed and published.	Test case results were already released, and no resources are available to complete requested documentation. *No change made to final NUREG.*
	NUREG should encourage use of peer reviews to increase confidence in performance assessment process.	*Final version of NUREG modified to recommend peer reviews and formal and informal use of expert judgment.*
	Potential for nuclear material criticality should be addressed	Staff considers potential for criticality to be remote and believes that appropriate measures will be taken during disposal facility operations. *No change made to final NUREG.*

a. *Refer to Appendix B to the final NUREG-1573 for a full discussion of the public comments received and their disposition.*
b. See Table D-1.

appendix) the Commission's 1995 PRA Policy Statement (as a new appendix)

Following a review and modification of NUREG-1573, the NRC briefed the ACNW on the proposed final document at its 119[th] meeting in June 2000. In its review, the ACNW received the document favorably, but did make certain recommendations for the Commission's consideration, as summarized in Table D-4 (Garrick, 2000).

D-4 REFERENCES

Adam, J.A., and V.L. Rogers, "A Classification System for Radioactive Waste Disposal - What Waste Goes Where?," U.S. Nuclear Regulatory Commission, NUREG-0456, July 1978.

Cady, R., and M. Thaggard, "Summary and Insights from the NRC Branch Technical Position Test Case," in *16[th] Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference (Abstracts), Phoenix, Arizona, December 13-15, 1994,* Idaho Falls, U.S. Department of Energy Idaho Operations Office, 1994.

Campbell, A.C., "Approaches for Uncertainty and Sensitivity Analysis in Performance Assessment," in *16[th] Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference (Abstracts), December 13-15, 1994, Phoenix, Arizona,* Idaho Falls, U.S. Department of Energy Idaho Operations Office, 1994.

Campbell, A.C., and T.J. McCartin, "Application of Geochemical Data and Modeling in Performance Assessment of Low-Level Radioactive Waste Disposal Facilities," *EOS [Transactions of the American Geophysical Union],* 75 (Supplement 16):171, 1994. [Spring meeting abstracts.]

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Chu, M.S.Y, M.W. Kozak, J.E. Campbell, and B.H. Thompson, "A Self-Teaching Curriculum for the NRC/SNL Low-Level Waste Performance Assessment Methodology," U.S. Nuclear Regulatory Commission, NUREG/CR-5539, January 1991. [Prepared by the SNL.]

Table D-4 **Summary of Staff Responses to ACNW Comments on NUREG-1573.** Taken from Appendix E to final NUREG. Refer to that appendix for a complete discussion of ACNW comments (Garrick, 2000) and their disposition.

ACNW Recommendation (Garrick, 2000)	Staff Response / NUREG-1573 Disposition
The document should be issued as a BTP.	The staff decision to issue the BTP as a NUREG reflects the need to make it clear that organizations (i.e., Agreement States, licensees) may take other approaches when implementing their respective programs. In addition, the staff believes that, given the agency's currently reduced role in licensing activities for LLW disposal, less need exists to provide specific guidance to licensees, which is the primary purpose of staff technical positions. *No change made to final NUREG.*
The staff should indicate in the technical report that a risk assessment is the acceptable method of safety analysis, the scope of which should be commensurate with the complexity of the facility.	*Final version of NUREG modified to address ACNW recommendation, including the Commission's 1995 PRA Policy Statement.*
The staff should provide guidance to the applicant to use realistic ranges and distributions of parameter values and conceptual models when conducting [probabilistic] risk analyses.	*Final version of NUREG modified to address ACNW recommendation.*
The staff should consider recommending a complementary cumulative distribution function type of an approach to treating uncertainty in a probabilistic interpretation of the dose standard.	The staff disagreed with the ACNW that the proposed approach for addressing uncertainty disregards all information about the distribution, except the mean and the 95th percentile. In the NUREG, the staff noted that it was envisioned that the whole distribution would be considered, so the recommended approach calls for looking at both the spread of doses at the time of the peak of the mean dose and the spread in peak doses. Although the staff agrees that it may be useful for the regulatory agency to see the whole distribution of results before making a finding on the compliance demonstration, ultimately, only part of the distribution will be used in determining compliance with the dose criteria, and guidance must be provided on what specific parts of the distribution should be used for this purpose. *No change made to final NUREG.*
The staff should consider eliminating the suggestion of a 500-year engineered barrier lifetime.	The staff agreed with the basic thrust of the ACNW recommendation, but declined to modify the NUREG. The staff considers the 500-year performance period to be useful guidance. In general, 500 years will be sufficient for the short-lived radionuclides in LLW to decay to insignificant levels. Because of the diminished radiological hazard at about 500 years and the limitations in data and experience in the performance of engineered barrier materials beyond 10^2 years, the staff believes that it is not necessary for LLW disposal facility developers to spend large amounts of resources trying to justify engineered barrier performance for periods beyond 500 years. Also, any decision regarding engineered barrier performance will need to ultimately rest with the LLW disposal facility developer, subject to an adequate technical basis. *No change made to final NUREG.*

ACNW Recommendation (Garrick, 2000)	Staff Response / NUREG-1573 Disposition
The decision on a timeframe for an LLW performance assessment should be made on a case-by-case basis.	The staff considered the earlier advice of the ACNW in its February 11, 1997, memorandum. In that advice (Pomeroy, 1997), the Committee recommended the use of a two-part approach to addressing the time-of-compliance issue. The staff believes that the use of such a two-part approach, as advocated by the Committee, is consistent with the approach recommended in the NUREG. *No change made to final NUREG.*

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APPENDIX E
SELECTED LOW-LEVEL RADIOACTIVE WASTE TECHNICAL REPORTS SPONSORED BY NRC'S OFFICE OF NUCLEAR REGULATORY RESEARCH

This appendix features a selected bibliography of low-level radioactive waste technical reports and papers sponsored by the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research since the publication of NUREG-1573, "A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities - Recommendations of NRC's Performance Assessment Working Group" in October 2000. The bibliography is annotated with the following codes to help identify the relevance of the particular citation, **BF** - barrier performance, **STC** - source term characterization, **DA** - dose assessment, **FM** - flow models, **RTM** - reactive transport models, and **TC** - transport calculations.

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APPENDIX F
FINAL COMMISSION POLICY STATEMENT ON THE USE OF PROBABILISTIC RISK ASSESSMENT METHODS IN NUCLEAR REGULATORY ACTIVITIES

F-1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) staff has been very active in the development of probabilistic risk assessment (PRA) technology and its application to nuclear facility safety. Landmarks of this activity include publication of the Reactor Safety Study - WASH-1400 (NRC, 1975), the transportation risk study (Fisher et al., 1977), nuclear power plant seismic hazard analyses (Bernreuter et al., 1989), and the nuclear power plants severe accident risk study, NUREG-1150 (NRC, 1990). In 1995, the Commission issued a policy statement that encouraged the [expanded] use of PRA methods as a complement to the deterministic approach taken in its nuclear regulatory activities.

The statement in Section F-2 presents the NRC policy for the use of PRA methods in nuclear regulatory matters. This agency developed this policy because it believed that the potential applications of PRA methodology could improve public health and safety decisionmaking while promoting stability and efficiency in the regulatory process and reducing unnecessary burdens on licensees. After a public workshop, the NRC published a draft Policy Statement dated December 8, 1994, at page 63389 of Volume 59 of the *Federal Register* (FR) (59 FR 63389). On receipt and consideration of public comments, the NRC published the final Policy Statement in 1995 (60 FR 42622).

F-2 THE COMMISSION POLICY STATEMENT (AT 60 FR 42628)

1. The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data and in a manner that complements NRC's deterministic approach and supports NRC's traditional defense-in-depth philosophy.

2. PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state of the art, to reduce the unnecessary conservatism associated with current regulatory requirements, regulatory guides, license commitments, and staff practices. Where appropriate, PRA should be used to support the proposal for additional regulatory requirements in accordance with Title 10, Part 50.109, "Backfit Rule," of the *Code of Federal Regulations* (10 CFR 50.109). Appropriate procedures for including PRA in the process for changing regulatory requirements should be developed and followed. It is, of course, understood that this policy intends that existing rules and regulations will be complied with until these rules and regulations are revised.

3. PRA evaluations in support of regulatory decisions should be as realistic as practicable, and appropriate supporting data should be publicly available for review.

4. The Commission's safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties in making regulatory judgments on the need for proposing and backfitting new generic requirements on nuclear power plant licensees.

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11. ABSTRACT *(200 words or less)*

The Advisory Committee on Nuclear Waste (ACNW or the Committee) examined issues associated with management and the disposal of commercial low-level radioactive waste (LLW). As a first step in that examination, the Committee developed this background document, or White Paper, that includes a review of the literature. This LLW White Paper is organized into three parts. Part I provides a historic perspective of past programs for the management and disposal of commercial LLW. Part II describes the U.S. Nuclear Regulatory Commission's commercial LLW regulatory framework found at Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," of the Code of Federal Regulations. Part III summarizes past ACNW advice in this area, as well as advice provided previously by the Advisory Committee on Reactor Safety before the establishment of the ACNW in 1988. This LLW White Paper also includes six appendices which, among other things, describe the Department of Energy's approach to the management of Government-owned LLW and the regulatory evolution of the "LLW" definition. The White Paper also identifies several emerging staff initiatives, as well as other ongoing initiatives by outside organizations and agencies that could have a bearing on the management of commercial LLW.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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greater-than-Class C radioactive waste
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mixed low-level radioactive waste
naturally occurring or accelerator-produced radioactive material
naturally occurring radioactive material
technologically-enhanced naturally occurring radioactive materials
transuranic radioactive waste

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