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Draft Generic Environmental Impact Statement
on decommissioning of nuclear facilities

U.S. Nuclear Regulatory Commission

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STUDY CONTRIBUTORS

The overall responsibility for the preparation of this report was assigned to the Fuel Process Systems Standards Branch of the Office of Standards Development, Nuclear Regulatory Commission (NRC). The report was prepared by NRC with input from Battelle Pacific Northwest Laboratories (PNL). Major contributors to this report were the following:

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FOREWORD

BY

NUCLEAR REGULATORY COMMISSION STAFF

The NRC staff is in the process of reappraising its regulatory position relative to the decommissioning of nuclear facilities.(1) The initial part of this activity consists of obtaining the information base to support any subsequent regulatory changes. Highly detailed studies are being completed, through technical assistance contracts, of the technology, safety and costs of decommissioning various nuclear facilities. (These studies are referenced in this document).

These studies were, in turn, utilized along with other information, to prepare this Draft Generic Environmental Statement on Decommissioning Nuclear Facilities. This statement is required because the regulatory changes that might result from the reevaluation of decommissioning policy may be a major NRC action affecting the quality of the human environment. Notice of intention to prepare a draft statement was given in Reference 1.

The information provided in this Statement, including any comments, will be included in the record for consideration by the Commission in establishing criteria and new standards for decommissioning. Persons wishing to comment on this Statement should mail their comments to:

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(1) Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities, NUREG-0436, Rev. 1, Office of Standards Development, U.S. Nuclear Regulatory Commission, December 1978, and Supplement 1, August 1980.

ABSTRACT

This draft generic environmental impact statement was prepared as part of the requirement for considering changes in regulations on decommissioning of commercial nuclear facilities (including that occurring following premature closure). Consideration is given to the decommissioning of pressurized water reactors, boiling water reactors, fuel reprocessing plants, mixed oxide fuel fabrication plants, uranium hexaflouride conversion plants, uranium fuel fabrication plants, independent spent fuel storage installations, nuclear energy centers, and facilities for handling non-fuel-cycle byproduct, source and special nuclear materials. Excluded here from consideration for regulation change, are decommissioning of shallow land low-level waste burial grounds, deep geologic high-level waste burial, and uranium mill and mill tailings which are being considered in seperate rulemaking activities, and decommissioning of uranium mines which are not under NRC jurisdiction. For decommissioning following postulated accidents, while the full data base on this subject is still under development, the basic purpose and objectives for decommissioning facilities involved in accidents would be the same as for routine decommissioning, although some of the specific aspects of the technology, safety and costs of decommissioning may differ.

Decommissioning has many positive environmental impacts such as the return of possibly valuable land to the public domain and the elimination of potential problems associated with increased numbers of radioactively contaminated facilities with a minimal use of resources. Major adverse impacts are shown to be routine occupational radiation doses and the committment of nominally small amounts of land to radioactive waste disposal. Other impacts, including public radiation doses, are minor. Mitigation of potential health, safety, and environmental impacts requires more specific and detailed regulatory guidance than is currently available. Recommendations are made as to regulatory decommissioning particulars including such aspects as appropriate initial planning requirements prior to commissioning, final planning requirements prior to termination of facility operations, residual radioactivity level for unrestricted access, and assurance of funding for decommissioning.

OVERVIEW

At the end of a commercial nuclear facility's useful life, termination of its license by the Nuclear Regulatory Commission (NRC) is a desired objective. Such termination requires that the facility be decommissioned. In decommissioning, radioactively contaminated materials present in the facility at the end of its useful life are appropriately removed such that the level of any residual radioactivity remaining after completion of decommissioning is low enough to allow unrestricted use of the facility and site. It is the objective of NRC regulatory activities in protecting public health and safety to provide to the applicant or licensee appropriate regulation and guidance for the implementation and accomplishment of nuclear facility decommissioning.

While decommissioning of most operating existing nuclear facilities is not imminent, it is anticipated that decommissioning of certain facilities may occur in the near future. Accordingly, the NRC is reevaluating its regulatory requirements concerning decommissioning policy. This draft generic environmental impact statement is part of this reevaluation since implementation of resultant regulations may have a significant impact on the environment.

PAST ACTIVITIES

In support of this reevaluation, a data base on the technology, safety, and cost of decommissioning various nuclear facilities by alternative methods is being completed for the NRC by Battelle Pacific Northwest Laboratory (PNL). Concurrent with these activities, a dialogue with the States, the public, and other government agencies has been maintained for critical commentary on the shaping and implementation of NRC decommissioning policy and its supportive technical information base. Based on such dialogue, NRC has modified and amplified its policy considerations and data base requirements in a manner responsive to comments received. Staff papers have been issued in two key areas of concern: (1) assurance that funds will be available for decommissioning, and (2) establishment of acceptable levels of residual radioactivity for release of facilities for unrestricted use. A third area of concern is the generic applicability of the data base for specific facility types. This has been addressed through expansion of the PNL facility reports to include sensitivity analyses for a variety of parameters potentially affecting safety and cost considerations.

SCOPE OF THE EIS

Regulatory changes are being considered for both fuel cycle and non-fuel-cycle nuclear facilities. The fuel cycle facilities are pressurized (PWR) and boiling water (BWR) light water reactors (LWRs) for both single and multiple reactor sites, fuel reprocessing plants (FRPs) (currently, use of FRPs has been indefinitely deferred in the commercial sector), small mixed oxide (MOX) fuel fabrication plants, uranium fuel fabrication plants (U-fab), uranium hexaflouride conversion plants (UF_6), and away-from-reactor independent spent fuel storage installations (ISFSI). Under non-fuel-cycle facilities, consideration is given to major types such as radiopharmaceutical or industrial radioisotope supplier facilities, various research radioisotope laboratories, and rare metal ore processing plants where uranium and thorium are concentrated in the tailings.

This EIS addresses only those issues involved in the activities carried out at the end of a nuclear facility's useful life which lead to unrestricted use of a facility. It does not address the considerations involved in extending the life of a nuclear facility. If a licensee makes an application for extending a facility license, it would be reviewed as an amendment to the existing license under appropriate existing regulations. This is not considered to be decommissioning and therefore is outside the scope of this EIS.

High-level waste repositories, low-level waste burial grounds, and uranium mills and their associated mill tailings piles are being covered in separate rulemaking activities and are not included here. The first two items are being considered in Title 10 of the Code of Federal Regulations (10 CFR) Parts 60 and 61. The last item is covered in a separate EIS and subsequent rulemaking proceedings.

Decommissioning that occurs as a result of premature closure due to accidents may involve technical and cost considerations not yet completely evaluated. Studies to develop a complete data base for this subject will begin in fiscal year 1981 and a detailed report on decommissioning following a postulated accident, similar to the report prepared for the facilities in this EIS, is expected to be issued in fiscal year 1982. While the basic purpose and objectives for decommissioning facilities involved in accidents would be the same as for routine decommissioning, some of the specific aspects of the techology, safety, and costs of decommissioning may differ. Nevertheless, in many instances, the specific aspects would have similarities between accident and routine decommissionings, in particular in areas such as decommissioning alternatives and timing, planning and facilitation, financial assurance, and residual radioactivity limits. It is not expected that major changes in the conclusions of this EIS will result from the technical studies on accident decommissioning, although there may be some differences in specific criteria. These items will be considered upon completion of the studies initiated in 1981.

REGULATORY OBJECTIVE

It is the responsibility of the NRC to insure,through regulations and other guidance, that appropriate procedures are followed in decommissioning such that the health and safety of the public is protected. Present regulatory requirements and guidance are not specific enough in many critical areas to ensure that potential problems are properly considered. Those areas include timeliness, financial assurance, planning, and residual radioactivity levels as discussed below:

Timeliness. It is the responsibility of the NRC, in protecting public health and safety, to ensure that after a nuclear facility ceases operation its license is terminated in a timely manner. Such termination requires decommissioning. From the analysis of the technical data base, it is clear that decommissioning can be accomplished safely and at modest cost shortly after cessation of facility operation and it is considered reasonable that decommissioning should be completed at this time. Completing decommissioning and releasing the facility for unrestricted use eliminates the potential problems of increased numbers of sites used for the confinement of radioactively contaminated materials, as well as potential health, safety, regulatory and economic problems associated with maintaining the site. Delay in the completion of decommissioning would be primarily for reasons of health and safety considerations, since it is recognized that with delay there may be reduction in occupational dose and radioactive waste volume for some facility types due to radioactive decay. Delay for such reduction would require additional justification since the amount of such reduction is of marginal significance in its effect on health and safety. For example, use of such delay may be justified at a multiple facility site where phased decommissioning may be appropriate. Even for this situation, decommissioning should be accomplished in as short a time as is reasonable. For this example, for a reactor at a multiple facility site where radioactive cobalt is the principle contaminant, there would be little dose reduction due to decay after a delay of 30 years. Therefore, it is recommended that the maximum delay for the reactor in this example be 30 years. For other facilities, the maximum delay considered reasonable will depend on the facility type and the contaminant isotopes involved.

Financial Assurance. Consistent with the regulatory objective of decommissioning as described above, a high degree of assurance is required from the nuclear facility licensee that adequate funds are available to decommission the facility. Because of the possibility of premature closure, a funding mechanism provided by the licensee must be in place which would pay for the full cost of decommissioning at any time during facility operation. The funding mechanisms considered reasonable for providing the necessary assurance include (singly or in combination) prepayment of funds into a segregated account, insurance, surety bonds, letters of credit, and a sinking fund deposited into a segregated account. Another funding mechanism that has drawn considerable interest, especially for reactors, is an internal reserve which uses negative net salvage value depreciation, and which generally is considered less expensive than other alternative funding mechanisms. However, the problem with such a mechanism is the lack of assurance it provides, by itself, that funds will be available for decommissioning. Moreover, while other funding mechanisms, such as prepayment or a sinking fund coupled with insurance, may be more costly on a net present worth basis, their economic impact is still small in terms of the total cost to the consumer or licensee. Therefore, under NRC's responsibility to protect public health and safety by assuring that funds are available for a safe decommissioning, the internal reserve would be considered an adequate funding mechanism only if it were supplemented by substantial additional funding mechanisms (such as insurance or some other surety arrangement) to increase the level of assurance.

Planning. Ensuring that decommissioning is appropriately accomplished requires careful planning. Decommissioning is affected by factors involved in the design and operation of a nuclear facility, as well as the actual operations carried out during the active decommissioning phase. Accordingly, it is important that the licensee decommissioning plan be developed and approved prior to commissioning of the facility. While such initial plan need not present the full detail for the actual decommissioning, it should contain sufficient detail on the cost of decommissioning and the method of funding. Moreover, it should address what will be done to facilitate decommissioning in terms of design and operation of the facility. While such considerations must include cost effectiveness, the emphasis should be on health and safety rather than economics. Certain aspects of decommissioning facilitation (such as those that have impact on reducing occupational dose during facility operation) can reduce operational costs. However, even those aspects of facilitation that are questionable in terms of reducing operational costs but can have significant impact on decommissioning health and safety aspects must be considered. Implementation of such possible facilitation at the design and construction stage can be much more cost effective than at the operational or active decommissioning stages.

Periodic updating of the initial decommissioning plan is required because of changes in factors affecting technology and cost. A final detailed decommissioning plan is required for review and approval by the NRC, and agreement states where applicable, prior to cessation of facility operation or shortly thereafter. Besides the technically detailed description of procedures, schedules, and work plans for the decommissioning alternative which will be used, the final plan should include a description of the termination survey required to certify that sufficient radioactively contaminated materials have been removed and that the facility can be released for unrestricted use. The plan should include an estimate of the cost required to accomplish the decommissioning.

Residual Radioactivity Levels. An important and technically difficult issue is the problem of determining acceptable residual radioactivity levels required for release of property for unrestricted use. It is the responsibility of the Environmental Protection Agency (EPA) to establish such a standard but it is not scheduled to do so until 1984. Discussions have been held with the EPA relative to providing preliminary guidance for NRC in establishing limits which are consistent with eventual EPA requirements. Due to the variety of facility types and radionuclides involved it is not feasible to set a single dose limit that would be valid under all conditions for all facilities. It is necessary to assess the radiological impact in terms of the radionuclides and pathways involved and the costs and benefits which result. Based on the considerations, on discussions with the EPA, and on considerations that the level of residual radioactivity selected must be safe and consistent with existing guidance and be measurable and cost effective, the following results were determined:

(1) A residual radioactivity level for permitting release of a nuclear facility for unrestricted use should be ALARA. Guidance in establishing such a limiting level is best expressed in terms of a value which bounds the dose for the majority of facilities discussed in this report. This value is determined to be 10 mrem/yr whole-body dose equivalent, but could be lower for specific facilities. The 10 mrem/yr limit

is chosen recognizing that it may be impractical and unnecessary in some cases to meet a 5 mrem/yr limit considered in previous discussions with EPA. This is because of cost-benefit considerations and problems in detectability, sampling, and/or exposure patterns. Discussion with EPA indicated that the 10 mrem/yr limiting value would not be considered unreasonable. In all cases, a dose limit above 1 mrem/yr would require justification. For a few situations, it is expected that residual limits will be outside the bounds of the 1 to 10 mrem/yr range. For these special situations, case-by-case analysis in terms of cost and benefit effectiveness will be required to establish appropriate limiting levels.

(2) For implementation of a residual radioactivity level, the dose value selected must be converted to a contaminated material concentration or activity for instrument measurability. Such conversion is done through the use of modeling and depends on what radionuclides are present and how they result in individual radioactivity exposure. Realistic exposure conditions should be used in such modeling, recognizing, for example, that dwelling occupancy is less than full time, that self shielding is an important exposure reducing factor, and that weathering reduces resuspension of the contaminated materials.

PRELIMINARY CONCLUSIONS ON DECOMMISSIONING IMPACTS

Consideration of the decommissioning data base and of the concerns for required regulatory activity has led to the following preliminary conclusions for public comment in the Draft Generic Environmental Impact Statement:

> The technical basis exists for performing decommissioning in a safe, efficient and timely manner. Decommissioning as used here means to safely remove contaminant radioactive material down to residual levels considered acceptable for permitting unrestricted use of a facility and its site. Decommissioning has major beneficial impact because it allows a nuclear facility which no longer has operational value to be made available for unrestricted use. Moreover, making the facility available for unrestricted use eliminates the potential problems of increased numbers of sites used for the confinement of radioactively contaminated materials, as well as potential health, safety, regulatory and economic problems, and also releases valuable industrial land that can be reused with great benefit. When properly performed, decommissioning has only minor adverse impact. These include: an occupational dose burden which is of marginal significance to health and safety and which is a small percent of such burden experienced over the operational life of a facility; a relatively modest cost compared to the net present worth of the commissioning cost; and the irreversible commitment of a small amount of land (primarily for low-level waste) at an appropriate radioactive waste burial facility.
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> Furthermore, it is concluded that the specific implementation of the considerations and recommendations discussed above in the areas of timeliness, financial assurance, planning, and residual radioactivity levels should be incorporated into existing regulations.

INCORPORATION OF EIS CONCLUSIONS IN REGULATIONS

It is recommended that specific implementation of regulatory activities be performed by rulemaking as amendments to existing regulations (i.e., 10 CFR Parts 30, 40, 50, 51, 70 and 72) rather than as a separate regulation solely covering decommissioning. Because decommissioning overlaps so many areas covered by present regulations, such incorporation would be more efficient. In addition, it is recommended that a policy statement be issued prior to rulemaking so that the principal thrust of these activities can be presented clearly and provide appropriate perspective to additional rulemaking activities.

ORGANIZATION OF THE EIS

Following this overview, a detailed summary section is presented which parallels, in format, the main body of the EIS. The summary is prepared in this manner so that the user can obtain a relatively complete picture of the EIS contents by reading the summary, and then go to the section of the main text of the EIS indicated by the summary for additional details. Sections 1 to 3 of the main text of the EIS contain material common to all the facilities considered and should be read for discussion of generic issues. Sections 4 to 14 contain specific facility considerations. These separate facility sections were kept as self-contained as possible, so that a user interested in a particular facility type need primarily read only that section, as well as introductory, generic, and policy sections. Section 15 contains details on how the conclusions of the EIS will affect regulatory policy considerations. The last section of this EIS is a glossary which provides the reader definitions of terms used in this report, including those used in a special sense in this report.

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0.0 SUMMARY

This summary is a fairly detailed summary of the EIS which parallels, in format, the main body of the report. It is intended to serve as an abbreviated version of the report. This is done so that the user can obtain a relatively complete picture of the report contents by reading the summary, and then go to the section of the main body of the report indicated by the summary for additional details. Also, costs and radiation doses from decommissioning major fuel cycle facilities have been summarized in tables 0.0-1 and 0.0-2 at the end of this summary section for the convenience of the reader. These doses and costs are, for the most part, taken from references 1 through 8, all of which are based on reports prepared by the Battelle Pacific Northwest Laboratory.

0.1 INTRODUCTION

Commercial nuclear facilities that come under the Nuclear Regulatory Commission's (NRC) regulatory authority include those dealing with fuel cycle and non-fuel-cycle operation, both of which require the handling of radioactive materials. The generation of electric power from steam supplied by nuclear reactors requires a series of support processes (and associated facilities) collectively known as the nuclear fuel cycle. This cycle begins with the mining and milling of uranium ore, includes the operation of power reactors, and ends with the disposition of radioactive wastes. Non-fuel-cycle facilities include those involved in pharmaceutical, academic and industrial radioisotopic use and in rare metal ore processing. While the safe operation of nuclear facilities (especially power reactors) and the safe disposition of radioactive waste have received much attention, the issue of decommissioning is now receiving an increasing amount of attention because a number of nuclear facilities are nearing the end of their useful lives. This document considers this issue.

0.1.1 PURPOSE OF EIS

The purpose of this environmental impact statement (EIS) is to assist the Nuclear Regulatory Commission in developing new policies and in promulgating new regulations with respect to the planned decommissioning of commercial nuclear facilities (including decommissioning due to premature closure of facilities). It is prepared pursuant to the requirements of the National Environmental Policy Act (NEPA). Excluded from these considerations are decommissioning activities for uranium mill and mill tailings, shallow land low-level waste burial, and deep geologic high-level waste burial which will be covered in separate rulemaking and uranium mines which are not under NRC jurisdiction.

Decommissioning that occurs as a result of premature closure due to accidents may involve technical and cost considerations not yet completely evaluated. Studies to develop a complete data base on this subject will begin in fiscal year 1981, with a detailed report on decommissioning following a postulated accident, similar to the reports prepared for the facilities in this EIS to be issued in fiscal year 1982. While the basic purpose and objectives for decommissioning facilities involved in accidents would be the same as for routine decommissioning, some of the specific aspects of the technology, safety, and costs of decommissioning may differ. Nevertheless, in many instances, these specific aspects would have similarities between accident and routine decommissionings, in particular, in areas such as decommissioning alternatives and timing, planning and facilitation, financial assurance, and residual radioactivity limits. It is not expected that major changes in the conclusions of this EIS will result from the technical studies on accident decommissioning, although there may be some differences in specific criteria. These items will be considered upon completion of the studies initiated in 1981.

0.1.1.1 NEPA Requirements

The National Environmental Policy Act (42 U.S.C. 4321 et seq.) requires that all agencies of the Federal Government include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on various particulars describing analysis of environmental impacts for the proposed activity.

0.1.2 ORGANIZATION OF THE EIS

The first three sections of this EIS contain material common to all of the facilities discussed in the statement. Regulatory matters are discussed in Section 1. Section 2 discusses in a generic manner the following: nuclear facilities; decommissioning alternatives; acceptable residual radioactivity levels for permitting release of the site for unrestricted use; financial assurance that sufficient funds are available for decommissioning; the management of radioactive wastes; and safeguards. Facility sites (i.e., the affected environment) are discussed generically in Section 3. Major facilities are discussed separately in Sections 4 through 14. These sections include descriptions of each facility, discussions of decommissioning alternatives, and summaries of radiation exposures and decommissioning costs. Other environmental consequences are also discussed. Regulatory policy considerations are discussed in Section 15.

Very detailed reports have been, or are being, prepared which constitute information bases on the technology, safety and costs of decommissioning of the nuclear facilities discussed in this report.(1-8) These facilities are pressurized water reactors, boiling water reactors, fuel reprocessing plants, small mixed oxide fuel fabrication plants, uranium hexafluoride conversion plants, uranium fuel fabrication plants, multiple reactor power stations, and non-fuel-cycle materials facilities.

0.1.3 PURPOSE OF DECOMMISSIONING

The purpose of decommissioning nuclear facilities is to take the facility safely from service and to remove or to isolate the associated radioactivity effectively from the environment so that the facility can be released for unrestricted use. Alternative methods of accomplishing this purpose, and the environmental impacts of each alternative are discussed in this EIS.

0.1.4 RESPONSIBILITY FOR DECOMMISSIONING

The responsibility for decommissioning a commercial nuclear facility belongs to the licensee. Regulatory and policy guidance for decommissioning is the responsibility of the NRC and is implemented either by the NRC or Agreement State as applicable. Preparation for and implementation of decommissioning, including cost, is a requirement of the licensee.

0.1.4.1 Existing Criteria and Regulations for Decommissioning

Statutory authority for the regulation of activities related to the commercial nuclear fuel cycle is contained in the Atomic Energy Act of 1954 and in its subsequent amendments as well as the 1974 Energy Reorganization Act.

Pursuant to these acts, the NRC has promulgated regulations which appear in Title 10 of the Code of Federal Regulations. The NRC has also published Regulatory Guides for the purpose of assisting applicants and licensees in carrying out their regulatory obligations.

Present decommissioning regulations are contained in 10 CFR Part 40 and in Section 50.33(f), Section 50.82, and Appendix F of 10 CFR Part 50. General guidance is contained in NRC Regulatory Guides 1.86 (concerning reactors) and 3.5 (rev. 1) (concerning uranium mills) and in other NRC staff guidelines.

A more detailed review of existing statutes, regulations, and guidelines appears in Reference 9.

0.1.4.2 Proposed Rulemaking

The NRC is currently considering developing a more explicit overall policy for decommissioning commercial nuclear facilities and amending its regulations in 10 CFR Chapter I to include more specific decommissioning guidance for production and utilization facility licensees and byproduct, source, and special nuclear material licensees.(10) Specific licensing requirements are being considered that include the development of decommissioning plans and financial arrangements for decommissioning all nuclear facilities. Preliminary staff views on such requirements have recently been presented.(11,12)

0.1.5 HISTORY, BACKGROUND, AND EXPERIENCE WITH DECOMMISSIONING

Since 1960, five licensed nuclear power reactors, four demonstration reactors and six licensed test reactors have been decommissioned. Only one reactor, the Elk River reactor, has been completely dismantled. Decommissioning experience with other nuclear fuel cycle facilities is very limited, although some experience has been gained with the decommissioning of military facilities and a variety of commercial and federally owned research facilities.

0.2 GENERIC NUCLEAR FACILITY DECOMMISSIONING CONSIDERATIONS

Consideration is given to generic items required for implementing a decommissioning program. After a brief overview of the operational role of nuclear facilities, discussion is presented on decommissioning alternatives, acceptable residual radioactivity levels for unrestricted access to a facility, financial assurance, decommissioning waste management, and safeguards.

0.2.1 NUCLEAR FACILITIES OPERATIONAL DESCRIPTION

0.2.1.1 The Nuclear Fuel Cycle

A nuclear power plant is a facility designed to generate electricity by utilizing the heat produced by controlled nuclear fission of uranium and plutonium. This is the desired production step in the fuel cycle. It is preceded by several steps in which uranium ore is processed into fuel elements, namely: mining, milling, conversion, and fabrication. It is followed by several steps in which fuel removed from the reactor is stored and then either reprocessed to recover usable fuel or disposed of in some manner. At present, spent fuel is being stored at the reactor sites as a result of the indefinite deferral of reprocessing and mixed oxide fuel fabrication and the continued study of ultimate (geologic) disposal.

0.2.1.2 Non-Fuel-Cycle Nuclear Facilities

Non-fuel-cycle facilities are those facilities which handle byproduct, source and/or special nuclear materials but which are not involved in the production of nuclear power. Non-fuel-cycle facilities must be licensed by the NRC. Precise definitions and licensing requirements for the materials listed above are published in 10 CFR Parts 30, 40, and 70, respectively. These facilities include a wide range of applications in industry, medicine and research such as manufacture of packaged products containing small sealed sources and of radiochemicals, research and development institutions, and processors of ores in which the tailings contain licensable quantities of radionuclides.

0.2.2 FACILITIES CONSIDERED IN EIS

The facilities considered in this EIS are: 1) pressurized water reactors, 2) boiling water reactors, 3) fuel reprocessing plants, 4) small mixed oxide fuel fabrication plants, 5) uranium hexafluoride conversion plants, 6) uranium fuel fabrication plants, 7) independent spent fuel storage installations, 8) nuclear energy centers, and 9) non-fuel-cycle nuclear facilities. The facilities not considered include uranium mills and mill tailings, and low-level waste and high-level waste burial grounds because they are covered by separate rulemaking; and uranium mines and the existing government owned uranium enrichment plants because they are not under NRC jurisdiction.

0.2.3 DEFINITION OF DECOMMISSIONING

Decommissioning means to safely remove the property from radioactive service and to dispose of radioactive materials. The level of any residual radioactivity remaining on the property after decommissioning must be low enough to allow unrestricted use of the property.

0.2.4 DECOMMISSIONING ALTERNATIVES

Once a nuclear facility has reached the end of its useful life, it must be decommissioned (i.e., placed in a condition such that there is no unreasonable risk from the decommissioned facility to public health and safety). Several alternatives are possible, although not all may be satisfactory for all nuclear facilities. These alternatives are: no action, DECON, SAFSTOR, and ENTOMB. The terms DECON, SAFSTOR, and ENTOMB are relatively new in use and are presented to end confusion with inconsistent nomeclature and meaning. These alternatives use procedures to remove radioactively contaminated materials down to residual levels which permit release of the facility for unrestricted access. DECON results in this unrestricted access shortly after the cessation of facility operations. SAFSTOR defers the release of the facility for unrestricted access until after a safe storage period. ENTOMB defers the unrestricted access of the facility until after an entombment period. SAFSTOR relies on a final decontamination to reach acceptable residual radioactivity levels after the radioactive decay which occurs during the safe storage period. ENTOMB relies primarily on radioactive decay for reaching acceptable levels.

Conversion to a new or modified use is also considered. Conversion, however, is not a true decommissioning alternative whether the new use involves radioactivity or not. If the intended new use involved radioactive material and, thus was under NRC licensing authority, an application for the new use would be reviewed as amendments to the existing license under appropriate existing regulations. If the intended new use does not involve radioactive material, i.e., unrestricted public access, and does not come under NRC licensing authority, then such application for a new use would be reviewed as a request for decommissioning and termination of license. As such, it would have to use one of the decommissioning alternatives indicated above, namely DECON, SAFSTOR, or ENTOMB. In this case, the new use is not important except as it affects the decommissioning alternative chosen and the evaluation of residual radioactivity levels for unrestricted facility use. For these reasons, conversion to a new or modified facility is not considered further in the EIS.

0.2.4.1 No Action

The objective of decommissioning is to return a radioactive facility to the public domain in a condition such that there is no unreasonable risk from the decommissioned facility to public health and safety. In order to ensure that at the end of its life the risk from a facility is within acceptable bounds, some action is required, even if it is as minimal as making a terminal radiation survey to verify the radioactivity levels and notifying the NRC of the results of the survey. Thus, independent of the type of facility and its level of contamination, No Action, implying that a licensee would simply abandon or leave a facility after ceasing operations, is not a viable decommissioning alternative. Therefore, since no action is not considered viable for any facility discussed in this EIS, this alternative is not considered further in this report.

0.2.4.2 DECON

DECON means to immediately remove all radioactive materials down to levels which are considered acceptable to permit the property to be released for unrestricted use. DECON is the only one of the decommissioning alternatives presented here which leads to termination of the facility license and release of the facility and site for unrestricted use shortly after cessation of facility operations. DECON is estimated to last from fairly short time periods for small facilities to up to approximately 4 years for a large PWR.

The primary advantage of DECON, which is terminating the facility license and making the facility and site available for some other beneficial use, is accomplished at the expense of larger initial commitments of money, personnel radiation exposure, and waste disposal site space than for the other alternatives. However, for some facilities, DECON results in less overall dose and cost. Other advantages of DECON include the availability of a work force highly knowledgeable about the facility and the elimination of the need for long-term security, maintenance and surveillance of the facility which would be required for the other decommissioning alternatives.

0.2.4.3 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a radioactive facility in such condition that the risk to safety is within acceptable bounds and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use. SAFSTOR consists of a short period of preparation for safe storage (up to 2 years), a variable safe storage period of continuing care consisting of security, surveillance, and maintenance (up to 100 years depending on the type of facility; 100 years is consistent with recommended EPA policy on institutional control reliance for radioactivity containment) and a short period of final decontamination. Several subcategories of SAFSTOR are possible. These subcategories are custodial, passive, or hardened SAFSTOR, the differences among them being the degree of cleanup and surveillance required.

SAFSTOR is used as a means to satisfy the requirements for protection of the public while minimizing the initial commitments of time, money, occupational radiation exposure, and waste disposal space. Modifications to the facilities are limited to those which ensure the security of the buildings against intruders, and to those required to ensure containment of radioactive or toxic material.

The reduced initial effort (and cost) of the preparation for safe storage is tempered somewhat by the need for continuing surveillance and physical security to ensure the protection of the public. Maintenance of the facility's structures and an ongoing program of environmental surveillance are also necessary. The duration of the storage and surveillance period can vary from a few years to approximately 100 years depending on the type of facility.

0.2.4.4 ENTOMB

ENTOMB means to encase and maintain property in a strong and structurally long-lived material (e.g., concrete) to assure retention until radioactivity decays to a level acceptable for releasing the facility for unrestricted use. ENTOMB is intended for use where the residual radioactivity will decay to levels permitting unrestricted release of the facility within reasonable time periods (i.e., within the time period of continued structural integrity of the entombing structure; approximately 100 years is considered to be consistent with recommended EPA policy on institutional control reliance for radioactivity containment). However, a few radioactive isotopes found in fuel reprocessing plants, nuclear reactors, fuel storage facilities, or MOX facilities have half-lives in excess of 100 years and the radioactivity will not decay to levels permitting release of the facilities for unrestricted use within the foreseeable lifetime of any man-made structure. Thus, the basic requirement of continued structural integrity of the entombment cannot be ensured for these facilities, and ENTOMB is not a viable alternative. On the other hand, if the entombing structure can be expected to last many half-lives of the most objectionable long-lived isotope, then ENTOMB becomes an viable alternative because of the reduced occupational and public exposure to radiation. ENTOMB does, of course, contribute to the problem of increased numbers of sites dedicated for very long periods to the containment of radioactive materials.

0.2.5 RESIDUAL RADIOACTIVITY LEVELS FOR RELEASE OF A FACILITY FOR UNRESTRICTED ACCESS

Decommissioning requires reduction of the radioactivity remaining in the facility to residual levels which are considered acceptable for permitting release of the facility for unrestricted access and for consequent NRC license termination. Preliminary NRC staff views on setting appropriate levels have recently been presented.(10,11,13)

0.2.5.1 Existing Regulations and Guidance

EPA has the formal responsibility for establishing a residual radioactivity level which is considered safe but is not scheduled to do so until 1984. Existing NRC and EPA regulations dealing with this subject are not specific enough.

0.2.5.2 Residual Radioactivity Limit Requirements

In addition to the requirement that a selected residual radioactivity limit be safe and consistent with existing regulations, it must be verifiable through detailed survey measurements, the effort of which must be consistent with the ALARA principle.

Acceptable residual radioactivity levels are needed by NRC for use in their decommissioning program reevaluation prior to the time of formal EPA issuance. The EPA has provided preliminary guidance to NRC on levels considered to be in an acceptable radiation dose range, requiring justification and using realistic dose-assessment methodology.

0.2.5.3 Implementation of Objectives

Due to the variety of facility types and radionuclides involved it is not feasible to set a single dose limit that would be valid under all conditions for all facilities. It is necessary to assess the radiological impact in terms of the radionuclides and pathways involved and the costs and benefits which result. B[illegible]n these considerations and on the above considerations that residual radioactivity levels permitting unre[illegible]cted facility access be consistent with previous guidance as well as current EPA guidance, and that these [illegible]ve the capability to be verified within the framework of the ALARA concept, the following recommendation [illegible]e:

(1) a residual radioactivity level for permitting release of a nuclear facility for unrestricted use should be ALARA. Guidance in establishing such a limiting level is best expressed in terms of a value which bounds the dose for the majority of facilities discussed in this report. This value is determined to be 10 mrem/yr whole-body dose equivalent, but could be lower for specific facilities. The 10 mrem/yr limit is chosen recognizing that it may be impractical and unnecessary in some cases to meet the 5 mrem/yr limit mentioned in conclusion 2 of Section 2.5.2 because of cost-benefit considerations and problems in detectability, sampling, and/or exposure patterns. Discussion with EPA indicated that the 10 mrem/yr limiting value would not be considered unreasonable. In all cases, a dose limit above 1 mrem/yr would require justification. For a few situations, it is expected that residual limits will be outside the bounds of the 1 to 10 mrem/yr range. For these special situations, case-by-case analysis in terms of cost and benefit effectiveness will be required to establish appropriate limiting levels.

(2) such dose rates and associated allowable contamination levels should be based on realistic dose assessment methodology.

By making use of the realistic pathway analysis, the choice of these residual radioactivity levels are consistent with current EPA(11) and previous NRC regulatory guidance (Regulatory Guide 1.86 concentration values converted to dose) and with the former AEC guidance and various decommissionings of AEC facilities. As indicated in Section 2.5.2, this realistic analysis is based on such factors as occupancy, shielding, radioactive decay, weathering, ingestion pathway, and resuspension. Consideration of these factors can be applied in order to convert the radiation levels as measured by the terminal radiation survey to a dose that a member of the public would realistically be expected to be exposed to from the decommissioned nuclear facility. In making this evaluation, situations are considered in which nuclear facilities, both for the case of a reactor and the case of a nonreactor facility, have been decommissioned, a certification survey of the facility and its site has been completed, and the facility and site are being considered as to their acceptability for being released for unrestricted use. In making the determination of acceptability, the NRC must consider the dose which the public may receive as a result of exposure from the decommissioned facility. Several potential uses of the decommissioned facility and its site, including industrial, farming, recreational, and residential uses, are considered to determine which would be limiting in terms of estimated dose to the public. For both reactor and nonreactor facilities, the limiting case is considered to be a housing development that might be constructed on the site. At the time of the certification survey it is assumed that the measurement of the site showed an exposure level consistent with instrument sensitivities given in Regulatory Guide 1.86 and in Appendix A of NUREG-0436.(10) Based on the consideration of the realistic factors discussed above, the realistic analysis of the dose to a member of the population, exposed to radiation levels corresponding to those of the cerification survey, would be within the 1-10 mrem/yr range.

Cost-benefit considerations are involved in the evaluation of the certification survey measurement capabilities and the extent of facility decontamination necessary to reduce radioactive contamination to levels considered acceptable for releasing the facility for unrestricted use. However, survey costs are expected to be small in comparison to the overall decommissioning costs, and decontamination costs of a facility are essentially independent of the level to which it must be decontaminated as long as that level is in the range of 1 to 25 mrem/yr to an exposed individual.(1),(3) Therefore, cost-benefit considerations are not expected to have a major impact on the GEIS results concerning reactor or most nonreactor decommissionings. Cost-benefit may be a consideration in the removal of ore piles at non-fuel-cycle ore processing facilities where cost of disposal of the ore is very large.

0.2.6 FINANCIAL ASSURANCE

The primary objective of the NRC with respect to nuclear facility decommissioning is to protect the health and safety of the public. An important aspect of this objective is to ensure that at the time of termination of facility operations (including premature closure) that adequate funds are available for decommissioning a facility resulting in its release for unrestricted access. Assurance of this availability of funds is necessary to ensure that a health and safety problem does not result because of undue delay in performing the required decommissioning. Satisfaction of the NRC objective requires that the applicant/licensee provide a high degree of assurance that adequate funds are available when needed.

0.2.6.1 Present Regulatory Guidance

Present regulatory guidance is not specific enough on required particulars needed to deal properly with financial assurance consideration. When such issues have been considered, they have been handled on a case-by-case basis as a condition of licensing or license renewal.

0.2.6.2 Implementation of Financial Assurance Requirements

In providing the high degree of assurance that funds are available for decommissioning, there are several possible funding mechanisms available to applicants and licensees. The wide diversity in types and complexity of nuclear facilities necessitates that NRC allow a wide latitude in the implementation of these funding mechanisms. Guidance as to what funding mechanisms provide adequate assurance has led to the following major classification of funding alternatives (used singly or in combination): (1) Prepayment; (2) Decommissioning insurance, surety bonds, letters of credit; and (3) Sinking Funds. Another potential funding mechanism is referred to as internal reserve. While it is generally considered that this mechanism is less costly than the others, it has deficiencies because of the lack of assurance it, by itself, provides that funds will be available for decommissioning. Under NRC's responsibility to protect public health and safety, it would be considered an adequate funding mechanism only if it were supplemented by substantial additional financing mechanisms (such as insurance of some other surety arrangement) that provided higher assurance.

It is concluded that whatever NRC approved funding mechanism is utilized, its impact will be minor on the public and industry, and be consistent with justifiable mitigation of potentially adverse impacts.

Suitable periodic review and updating of the licensee funding mechanism would be required to reflect the progressive evolution of decommissioning information that affects funding.

0.2.7 MANAGEMENT OF RADIOACTIVE WASTES AND INTERIM STORAGE

Decommissioning of a nuclear facility results in the generation of radioactive waste which must be disposed of at a waste disposal site. In any given year the quantity of this waste generated by decommissioning will be considerably less than that generated by operating nuclear facilities. Hence, should some future problem in waste disposal capacity occur, it will be the result primarily of operating nuclear facility waste inputs rather than decommissioning wastes. Nevertheless, at the time of decommissioning, contingency provision should be provided by the licensee for interim storage of decommissioning wastes if permanent waste disposal capacity is unavailable.

0.2.8 SAFEGUARDS

Safeguard measures may be required during the active decommissioning stage (through to unrestricted access) depending on the quantity and type of material present. During the initial decommissioning stages these requirements may be the same as during the operational stage. Decreasing levels of safeguards measures will be required until all the special nuclear materials have been reduced below safeguards quantities.

0.3 AFFECTED ENVIRONMENT - GENERIC SITE DESCRIPTION

Section 3 of the GEIS presents the generic site description of a fuel cycle facility site. It is considered representative of the potential site of a nuclear installation and is used for all facilities in the GEIS except the non-fuel-cycle facilities.

0.4 PRESSURIZED WATER REACTOR

A pressurized water reactor (PWR) is a facility for converting the thermal energy of a nuclear reaction into steam to drive a turbine-generator and produce electricity. The conversion is accomplished by heating water to a high temperature and pressure in the reactor pressure vessel, using the pressurized hot water to produce steam in the steam generator, and driving the turbine-generator with the steam.

Much of what follows is based on the NRC-sponsored Pacific Northwest Laboratory (PNL) study on the technology, safety and cost of decommissioning a reference PWR(1) at the end of its operating life. Also, as part of an addendum to this study, PNL did a sensitivity study to analyze the effect that varying certain parameters might have on the conclusions in the original study regarding doses and costs of decommissioning. The parameters which were varied in the addendum included reactor size, degree of radioactive contamination, decommissioning alternatives, etc.

0.4.1 PWR DESCRIPTION

The major components of a PWR are a reactor core and pressure vessel, steam generators, steam turbines, an electric generator, and a steam condenser system. Water is heated to a high temperature under pressure inside the reactor and is then pumped in the primary circulation loop to the steam generator. Within the steam generator, water in the secondary circulation loop is converted to steam that drives the turbines. The turbines turn the generator to produce electricity. The steam leaving the turbines is condensed by water in the tertiary loop and returned to the steam generator. The tertiary loop water then flows to cooling towers where it is, in turn, cooled by evaporation. The tertiary loop is open to the atmosphere, but the primary and secondary cooling loops are not.

The major radiation problems in decommissioning are associated with the reactor itself, the primary loop, the steam generators, the radioactive waste handling systems, and the concrete biological shield that surrounds the pressure vessel.

0.4 2 PWR DECOMMISSIONING EXPERIENCE

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled. Though this reactor was quite small compared to present day commercial power reactors, one lesson stands out: a reactor can be decontaminated with reasonable occupational radiation exposure and with virtually no public radiation exposure.

Other power reactors, all of them relatively small, have been placed in safe storage or entombed. These methods of decommissioning require some sort of surveillance and also require retention of a possession-only license. In the case of the Elk River reactor, all licenses were terminated.

0.4.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

0.4.3.1 DECON

DECON results in the release of the site and any remaining structures for unrestricted use as early as 4 years after the cessation of reactor operation.

The PNL study shows that the total DECON effort would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost $33.3 million in 1978 dollars, including $8[illegible],000 for deep geologic disposal of activated components. For comparison purposes, the time to plan and build a large power reactor is presently at least 12 years, and the cost is well over one billion dollars.

The occupational radiation dose from external exposure to surface contamination and activated material, not including transportation of radioactive waste, was estimated to be 1083 man-rem over 4 years (an average of 270 man-rem per year). The occupational radiation dose from the transportation of radioactive wastes was calculated to be 99.[illegible] man-rem to truck transportation workers from waste shipments. For comparison purposes, the annual occupational radiation dose from operation, maintenance, and refueling of PWRs from 1969 through 1975 was 430 man-rem per reactor.(14)

The radiation dose to the public from airborne radionuclide releases during DECON was estimated to be negligible. The radiation dose to the public was calculated to be about 20.5 man-rem from the truck transportation of radioactive wastes.

0.4.3.2 SAFSTOR

The purpose of SAFSTOR is to permit ^{60}Co to decay to levels that will reduce occupational radiation exposure during decontamination. In contrast to DECON, SAFSTOR could include a safe storage period as long as 30 to 100 years before final decontamination. The end result is the same: release of the site and remaining structures for unrestricted use.

The PNL study shows that the costs of SAFSTOR are greater than those of DECON and vary with the number of years of safe storage. The total cost of 30-year SAFSTOR was estimated to be $42.8 million in 1978 dollars, and the total cost of 100-year SAFSTOR was estimated to be $41.8 million in 1978 dollars.

SAFSTOR results in lower radiation doses to both the work force and to the public. The PNL study shows the occupational radiation dose to be a total of approximately 317 man-rem for 30-year SAFSTOR not including transportation. The occupational radiation dose from the truck transportation of radioactive wastes was calculated to be about 1[illegible] man-rem. There is little additional reduction in occupational radiation dose as a result of using 100-year SAFSTOR.

Radiation doses to the public from airborne radionuclide releases resulting from preparation for safe storage were estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes was calculated to be about 2.5 man-rem.

0.4.3.3 ENTOMB

ENTOMB uses massive concrete and metal barriers until the radioactivity has decayed to levels permitting unrestricted facility use. In ENTOMB, the length of time the integrity of the entombing structure must be maintained depends on the inventory of radioactive nuclides present. If a PWR has been operated for 30 or 40 years, substantial amounts of ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives) will have been accumulated as activation products in the reactor vessel internals. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 2 rem/hour (about 17,000 rem/year) while the dose from the ^{59}Ni in the internals is 0.1 rem/hour (about 880 rem/year). These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lives of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. Thus, the long-lived isotopes will have to be removed or the integrity of the entombing structure will have to be maintained for many thousands of years.

ENTOMB of a PWR is limited to the containment building because of its unique structure. The other buildings associated with a reactor must be decommissioned by another method such as DECON.

PNL considered two approaches to entombment.(1) In the first approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are entombed along with other radioactive material. This will result in the requirement for a possession-only license and surveillance in perpetuity because of the presence of the long-lived isotopes. In the second approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are removed, dismantled, and transported to a radioactive waste repository. This results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility to unrestricted use.

ENTOMB of the reference PWR, including the pressure vessel and its internals, was estimated to cost $21 million, with an annual maintenance cost of $40,000, and to result in a total radiation dose of 900 man-rem to decommissioning workers, 20 man-rem to transportation workers, and 3 man-rem to the general public. ENTOMB of the reference PWR, with the pressure vessel internals removed, was estimated to cost $27 million, with an annual maintenance cost of $40,000, and to result in a total radiation dose of 1000 man-rem to decommissioning workers, 25 man-rem to transportation workers, and 4 man-rem to the general public.

0.4.3.4 Sensitivity Analyses

An addendum to the PNL study was developed(1) to analyze a variety of realistic decommissioning situations that might significantly impact on the original conclusions regarding doses and costs for various decommissioning alternatives such as the sensitivity of decommissioning costs and radiation doses to reactor size.

The addendum also analyzed the sensitivity of decommissioning costs to a postulated tripling of radiation dose rates from radionuclides deposited in PWR coolant system piping during reactor operation, this level being considered an upper limit on the basis of recent trends for operating reactors. On the basis of the estimates made, it appears that additional chemical decontamination would be the most cost-effective approach to handling the higher radiation levels postulated, in addition to being consistent with the ALARA principle.

While there were some differences in results, the conclusion of the sensitivity analyses is that these differences do not substantially affect the cost and radiation dose conclusions of the generic study.

0.4.4 OTHER ENVIRONMENTAL CONSEQUENCES

The major environmental consequence of decommissioning, other than radiation dose and dollar cost, is the commitment of land area to the disposal of radioactive waste. PNL made the estimates shown in Table 0.4-1 of the burial volume of low-level radioactive waste and rubble that would need to be removed from the facility and transported to a licensed site for disposal.

TABLE 0.4-1 Burial Volume of Low-Level Radioactive Waste and Rubble for a PWR

Decommissioning Alternative	Volume (m^3)
DECON	17 900
SAFSTOR	
Deferred Decontamination	
for: 10 years	17 900
30 years	17 900(b)
50 years	1 830
100 years	1 740
ENTOMB(a)	1 740

(a) Does not include the volume of the entombing structure or of the wastes entombed within. The entombing structure is in effect a new radioactive waste burial ground.

(b) Although, in actuality, there is a more gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

If shallow-land burial of radioactive wastes in standard trenches is assumed, then 17,900 m^3 of radioactive waste can be disposed of in less than two acres, which is not large in comparison with the 1,160 acres originally used as the site of the reference PWR.

It is likely that certain highly activated components of the reactor and its internals will be placed in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very long half-lives of ^{59}Ni and ^{94}Nb. Only approximately 11 m^3 of material would be involved, but deep geologic disposal would add approximately $850,000 to the cost of decommissioning and would require approximately 88 m^3 of waste disposal space. This number has been included in the total cost of decommissioning.

0.4.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES (See Tables 0.0-1 and 0.0-2)

It appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a PWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger occupational radiation dose is considered of marginal significance to health and safety, and, therefore, DECON would be considered the more preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR.

Either ENTOMB option requires long-term dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay so this option is not viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory uncertainty after the long entombment time period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

0.5 BOILING WATER REACTOR

A boiling water reactor (BWR), like a pressurized water reactor (PWR), is a facility for converting the thermal energy of a nuclear reaction into the kinetic energy of steam to drive a turbine-generator and produce electricity. In a BWR, the conversion is accomplished by heating water to boiling in the reactor pressure vessel and using the resulting steam to drive the turbines. The intermediate step, present in a PWR, of converting pressurized hot water into steam through a heat exchanger in a steam generator is not part of a BWR.

In this section, we have used information prepared for the study on the technology, safety and costs of decommissioning a reference BWR at the end of its operating life, which was conducted by Pacific Northwest Laboratory (PNL) for the NRC.(2) In addition, as part of this study, PNL did a sensitivity study to analyze the effect that variation of certain parameters might have on doses and costs of decommissioning. The parameters which were varied included reactor size, degree of radioactive contamination, type of containment structure, etc.

0.5.1 BOILING WATER REACTOR DESCRIPTION

The major components of a BWR are a reactor core and pressure vessel, steam turbines, an electric generator, and a steam condenser system. Water is boiled in the reactor pressure vessel to create steam at high temperature and pressure, which then passes through the primary circulation loop to drive the turbines. The turbines turn the generator which produces electricity. The steam leaving the turbines is condensed by water in the secondary loop and flows back to the reactor. The water in the secondary loop flows to the cooling towers where it is in turn cooled by evaporation. The secondary cooling loop is open to the atmosphere, but the primary loop is not.

Buildings or structures associated with the reference BWR include 1) the reactor building which houses the reactor pressure vessel, the containment structure, the biological shield, new and spent fuel pools, and fuel handling equipment; 2) the turbine generator building which houses the turbines and electric generator; 3) the radwaste and control building which houses the solid, liquid, and gaseous radioactive waste treatment systems, and the main control room; 4) the cooling towers; 5) the diesel generator building which houses auxiliary diesel generators; 6) water intake structures and pump houses; 7) the service building which houses the makeup water treatment system, machine shops, and offices; and 8) other minor structures.

The major sources of radiation in decommissioning a BWR are associated with the reactor itself, the containment structure, the concrete biological shield, the primary loop, the turbines, and the radwaste handling systems.

0.5.2 BWR DECOMMISSIONING EXPERIENCE

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled. While this reactor was quite small compared to present-day power reactors, its decommissioning served to demonstrate a reactor can be decontaminated safely with little occupational or public risk.

Other reactors, all of them relatively small, have been placed in safe storage or entombed. Safe storage and entombment require surveillance and retention of a possession-only license. At Elk River, all licenses were terminated.

0.5.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

0.5.3.1 DECON

DECON results in the release of the site and any remaining structures for unrestricted use as early as 4 years after cessation of reactor operation.

The PNL study shows that the total DECON effort would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost $43.6 million in 1978 dollars. In comparison, the time to plan and build a large power reactor in the United States is presently at least 12 years and the cost is well over one billion dollars.

The occupational radiation dose from external exposure, not including transportation of radioactive waste, is estimated to be 1845 man-rem over 4 years (an average of 460 man-rem per year). The occupational radiation dose to truck transportation workers from DECON waste shipments is estimated to be 110 man-rem. In comparison, the annual occupational radiation dose of BWRs from 1969 through 1975 was approximately 340 man-rem per reactor.(14)

The radiation dose to the public from DECON activities is estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes from DECON is estimated to be 10 man-rem.

The major reason for the differences in cost and radiation dose between DECON of a BWR and a PWR is the requirement to dismantle, remove, and dispose of the turbine, condenser, and main steam piping which are somewhat more radioactive in a BWR than a PWR.

0.5.3.2 SAFSTOR

The purpose of SAFSTOR is to permit residual radioactivity to decay to levels that will reduce occupational radiation dose during decontamination. In SAFSTOR, the safe storage period could be as long as 30 to 100 years, before final decontamination. The end result is the same as that of DECON, the release of the site and any remaining structures for unrestricted use.

The PNL study shows that the costs of SAFSTOR are greater than those of DECON and vary with the number of years of safe storage. The total cost of 30-year SAFSTOR is estimated to be $58.9 million in 1978 dollars, and the total cost of 100-year SAFSTOR is estimated to be $55.0 million.

SAFSTOR results in lower radiation dose to both the work force and the public. The total occupational radiation dose is estimated to be 418 man-rem for 30-year SAFSTOR not including tranportation. The occupational radiation dose from the truck transportation of radioactive wastes is estimated to be about 24 man-rem. For 100-year SAFSTOR the total estimated occupational radiation dose is 385 man-rem. The occupational radiation dose from truck transportation of radioactive wastes is estimated to be 22 man-rem. As can be seen, there is little additional reduction in occupational radiation dose as a result of using 100-year SAFSTOR.

Radiation doses to the public from SAFSTOR activities are estimated to be negligible. The radiation dose to the public from truck transportation of radioactive wastes during the preparation for safe storage is estimated to be 2 man-rem, and that from truck transportation of radioactive wastes during deferred decontamination after 30 and 100 years of safe storage is estimated to be negligible.

0.5.3.3 ENTOMB

For ENTOMB, as in the case of the PWR, even though the Co^{60} with a 5.27-year half-life is the main contributor to dose, ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives) will have accumulated to significant levels in the reactor vessel internals after a few years of operation. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 0.7 rem/hour (about 6,100 rem/year) while the dose from the ^{59}Ni in the internals is 0.07 rem/hour (about 600 rem/year). These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lives of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. Thus, the long-lived isotopes will have to be removed or the integrity of the entombing structure would have to be maintained for many thousands of years.

ENTOMB of a BWR is limited to the containment vessel because of its unique structure. The other buildings associated with a reactor must be decommissioned by another alternative such as DECON.

Two approaches to ENTOMB for a BWR are possible. In the first approach, the pressure vessel internals with their long-lived isotopes are entombed. This will result in the requirement for a possession-only license and surveillance indefinitely because of the presence of the long-lived isotopes. In the second approach, the pressure vessel internals are removed, dismantled, and transported to a radioactive waste repository. This results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility to unrestricted use.

ENTOMB of the reference BWR, including pressure vessel and internals, is estimated to cost \$35.0 million, with an annual surveillance and maintenance cost of \$40,000, and to result in a total radiation dose of 1573 man-rem to decommissioning workers, 51 man-rem to transportation workers, and 5 man-rem to the general public. ENTOMB of the reference BWR, with the pressure vessel and internals removed, is estimated to cost \$40.6 million with an annual surveillance and maintenance cost of \$40,000, and to result in a total radiation dose of 1684 man-rem to decommissioning workers, 69 man-rem to transportation workers, and 7 man-rem to the general public.

0.5.3.4 Sensitivity Analyses

Analyses of the sensitivity of decommissioning costs and radiation doses to such parameters as reactor size were carried out by PNL. While there were some differences in results, the conclusion of the sensitivity analysis is that these differences do not substantially affect the cost and radiation dose conclusions of the generic study. Also analyzed was the sensitivity of decommissioning costs to a postulated tripling of radiation dose rates from radionuclides deposited in BWR coolant system piping during reactor operation, this level being considered an upper limit on the basis of recent trends for operating reactors. On the basis of the estimates made, it appears that additional chemical decontamination would be the most cost-effective approach to handling the higher initial radiation levels postulated, in addition to being consistent with the ALARA principle.

0.5.4 OTHER ENVIRONMENTAL CONSEQUENCES

A major environmental consequence of decommissioning is the commitment of land area to the disposal of radioactive waste. Estimates are shown in Table 0.5-1 of the waste disposal volume required to accommodate low-level radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. The volume for ENTOMB does not include the volume of the entombing structure or of the wastes entombed within.

If shallow-land burial of radioactive wastes in standard trenches is assumed, then a burial volume of 18,900 m^3 can be accommodated in less than 2 acres, which is not large in comparison with the 1160 acres originally used as the site of the reference BWR.

TABLE 0.5-1 Burial Volume of Low-Level Radioactive Waste and Rubble for a BWR

Mode	Volume (m^3)
DECON	18 900
SAFSTOR	
Deferred Decontamination	
for: 10 Years	18 900[b]
30 Years	18 900
50 Years	1 780
100 Years	1 670
ENTOMB[a]	
Internals Included	8 046
Internals Removed	8 420

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[a] Volume of entombing structure and wastes are not included. The entombing structure is in effect a new radioactive waste burial ground.

[b] Although, in actuality, there is a more gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

It is likely that certain highly activated components of the reactor and its internals will be placed in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very long half-lives of ^{59}Ni and ^{94}Nb. Only approximately 11^3 of material would be involved, but deep geologic disposal would add approximately $850,000 to the cost of decommissioning and would require 89 m^3 of waste disposal space.

0.5.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES (See Tables 0.0-1 and 0.0-2)

It appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a BWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger occupational radiation dose in considered of marginal significance to health and safety, and therefore, DECON would be considered the more preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR.

Either ENTOMB option requires long-term dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay so this option is not viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory uncertainty after the long entombment time period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

0.6 URANIUM MILL AND TAILINGS PILE

Decommissioning of uranium mills and tailings piles is considered in the draft EIS on uranium milling.(10)

0.7 FUEL REPROCESSING PLANT

A fuel reprocessing plant (FRP) is a facility for reclaiming plutonium and uranium from spent nuclear reactor fuel, so that the reclaimed plutonium and uranium can be later refabricated into new fuel elements.

This section is based primarily on a detailed study(3) of the decommissioning of a fuel reprocessing plant conducted by Pacific Northwest Laboratory (PNL) for the NRC. PNL developed and reported information on the available technology, safety considerations, and probable costs for decommissioning a reference facility at the end of its operating life.

0.7.1 DESCRIPTION OF FUEL REPROCESSING PROCESS AND FACILITY

0.7.1.1 Process Description

The reference plant uses the Purex process to recover plutonium and uranium from irradiated LWR fuels.

The irradiated fuel is received in heavily shielded casks and is unloaded and stored underwater in the fuel receiving and storage station. When ready for processing, each fuel assembly is transferred to the main process building where it is partly disassembled, chopped into pieces up to 10 cm long and dropped into a dissolver vessel where the fuel materials are dissolved with nitric acid. The undissolved fuel cladding hulls are packaged and taken to a bunker-type storage area onsite.

The nitric acid-fuel solution is then subjected to a solvent extraction process where the uranium, plutonium, and fission products are separated into individual streams, and the uranium and plutonium are purified and converted to uranium hexafluoride and plutonium oxide for offsite shipment. The fission products are stored in underground water-cooled tanks for about 5 years and then solidified for disposal at a Federal facility.

0.7.1.2 Plant Description

The major facilities included in the reference reprocessing plant are: 1) the fuel receiving and storage station, 2) the main process building, 3) the high- and intermediate-level liquid waste storage area, 4) the waste solidification plant, and 5) the radioactive auxiliary service areas.

0.7.1.3 Estimates of Radioactivity Levels at FRP Shutdown

Estimates of radioactivity levels in the reference fuel reprocessing plant after reprocessing operations have been terminated (all spent fuel removed) and final operational cleanout flushings of the process areas have been completed are summarized in Reference 3.

0.7.2 FUEL REPROCESSING PLANT DECOMMISSIONING EXPERIENCE

To date, there has been no experience in the decommissioning of a commercial FRP. Federal facilities at the Hanford, Savannah River, and Oak Ridge sites that have been involved with the reprocessing of irradiated fuels have been decontaminated and their equipment disassembled.(3) A substantial amount of this information is directly relatable to decontamination of future fuel reprocessing plants.

The Nuclear Fuel Services (NFS) plant in West Valley, New York, is the only commercial reprocessing plant that has operated in the United States. The NFS situation is not directly translatable to the present or projected nuclear power industry due to differences in regulation and waste handling procedures. Therefore, the costs of decommissioning this plant are expected to be higher than that of newer FRPs.

0.7.3 DECOMMISSIONING ALTERNATIVES

Alternatives include DECON, SAFSTOR, and ENTOMB.

0.7.3.1 DECON

For the DECON alternative, the end result is the release of the site and any remaining structures for unrestricted use as early as the 5 years estimated for decommissioning after the end of facility operation.

The occupational radiation dose from external exposure to radioactive materials, not including transportation of radioactive waste, is estimated to be about 512 man-rem over the 5-year period of DECON. The radiation dose to the public resulting from radionuclide releases during DECON, not including doses during transportation of radioactive waste, is estimated to be 10.2 man-rem.

The estimated radiation doses due to external exposure from rail and truck transport of radioactive wastes are 20 man-rem to the transportation workers and 9 man-rem to the public.

0.7.3.2 SAFSTOR

The major purpose of SAFSTOR is to permit residual radioactivity levels to decay to levels that will reduce occupational radiation exposure during decontamination. Most of occupational dose reduction due to decay occurs during the first 100 years after shutdown with lesser reduction thereafter. The public dose which is small to begin with, also experiences most of its reduction during the first 100 years. Hence, in contrast to DECON, to take advantage of this dose reduction, the safe storage period could be as long as 30 to 100 years. The end result is the same as for DECON: release of the site and any remaining structures for unrestricted use.

Two different subcategories for the SAFSTOR alternative are considered for the FRP. These are passive and custodial safe storage cases. For the passive case, for periods of 30 and 100-year safe storage, the total occupational doses are 312 and 138 man-rem. Doses due to transportation of wastes are for 12 and 5 man-rem, respectively. Doses to the public are small and for the 30- and 100-year safe storage periods are 10 and 4 man-rem, with transportation of wastes accounting for 5 and 2 man-rem of these respective results. The custodial care case gives slightly higher occupational doses with all other doses (including transportation) being the same.

0.7.3.3 ENTOMB

ENTOMB uses a structure to hold or confine the radioactivity until such time as it has decayed to levels which permit release of the facility for unrestricted use. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radionuclides present. The FRP contains long-lived transuranic radionuclides such as ^{239}Pu with a half-life of 24,390 years and the entombed structure would, in effect, become a new surface waste disposal site. This would be an undesirable situation in that it would be contributing to the problems associated with increased numbers of such waste disposal sites. Moreover, the entombed structure would require surveillance in perpetuity which is well beyond the time that the required institutional control could be expected to be effective (approximately 100 years is considered to be consistent with recommended EPA policy on institutional control reliance for radioactivity confinement).

ENTOMB is estimated to result in total occupational doses of 170 man-rem. The public dose from both plant releases and transportation is small.

0.7.3.4 Site Decommissioning

The residual contamination of the FRP site resulting from past operation and subsequent decommissioning is expected to be very low.

0.7.3.5 Summary of Radiation Safety

An advantage of DECON is that it results in the release of the site for unrestricted use within about 5 years after shutdown of plant operations. DECON has higher estimated occupational radiation exposure (512 man-rem) than the other alternatives. Depending on the length of the continuing care period, both passive and custodial SAFSTOR can result in an occupational dose reduction the magnitude of which is considered to be of marginal significance to health and safety. ENTOMB results in lower occupational exposures than DECON and 30-year SAFSTOR but higher exposures than 100-year SAFSTOR.

Radiation doses to the public from decommissioning operations and transportation of contaminated materials are all low, with a maximum of 19 man-rem due to DECON.

0.7.3.6 Decommissioning Costs

An estimate of the costs of decommissioning the FRP by each of the principal alternatives is presented below.

0.7.3.6.1 Detailed Costs

Reference 3 presents a discussion of decommissioning costs and their bases.

0.7.3.6.2 Summary of Costs

Table 0.7.3-1 summarizes the estimated costs for each decommissioning alternative.

TABLE 0.7.3-1. Summary of Estimated Costs for Decommissioning a Fuel Reprocessing Plant (1978 $ millions)

	DECON	SAFSTOR (passive)				SAFSTOR (custodial)				
Item		10 Years	30 Years	100 Years	200 Years	10 Years	30 Years	100 Years	200 Years	ENTOMB
Initial Decommissioning	76	24	24	24	24	23	23	23	23	37
Continuing Care(a)	--	2	6	18	22	8	26	88	176	.04/yr.
Deferred Decontamination	--	57	57	57	57	56	56	56	56	--
Total Costs (rounded)	76	83	87	99	103	88	105	167	255	37(b)

(a) Continuing care costs for passive storage are estimated to decline with the years to about $40,000 per year for the last 100 years; $18 million for the first 100 years is a conservative estimate.

(b) Add $40,000 per year for surveillance, monitoring, and maintenance.

ENTOMB requires some surveillance of the approximately 1-2 acres in perpetuity, with costs estimated to be about $40,000 per year. An initial look at Table 0.7.3-1 makes ENTOMB appear to be the lowest cost of the four options. However, when the cost of perpetual care is included (for a 24,390 year half-life radionuclide such as Pu-239) this advantage soon disappears.

0.7.4 ENVIRONMENTAL CONSEQUENCES

0.7.4.1 Wastes

Complete decontamination of an FRP requires about 0.4 hectare (1 acre) of land for final storage of the contaminated materials removed from the site. The high-level radioactive and TRU wastes will require about 4,600 m^3 in an expensive deep geologic disposal facility. This is equivalent to 163,500 cubic feet mined from either salt or basalt. The low-level and non-TRU wastes will require about 0.16 hectares (0.4 acre) of shallow-land burial area. These are considered irretrievable uses of land.

ENTOMB results in a large reduction (about 75% of DECON) in wastes to be buried in deep geologic storage. However, these procedures convert the entombed structure to a high-level waste burial ground and the volume of this waste is not included in this comparison. Wastes for shallow-land burial are also reduced, but to a smaller extent (about 35%). The entombed structure becomes a waste burial ground with the inclusion of high- and low-level waste.

0.7.4.2 Nonradiological Safety Impacts

The nonradiological hazards involved in the decommissioning of an FRP were reviewed on the basis of hazards to be found in both the chemical and construction industries and found to be insignificant.

0.7.4.3 Socio-Economic Impacts

The major societal impacts occur prior to decommissioning with the shutdown of the plant. Decommissioning tends to mitigate the impacts due to plant shutdown.

0.7.4.4 Comparison of Decommissioning Alternatives (See Tables 0.0-1 and 0.0-2)

The primary advantage of DECON is that the site and facility can be released for unrestricted use 5 years after the shutdown of the plant, and therefore, DECON is considered to be a preferred alternative since it costs less than SAFSTOR and since the occupational dose reduction by SAFSTOR is of an amount considered of marginal significance to health and safety. Both 30-year SAFSTOR and 100-year SAFSTOR may be reasonable options for reducing occupational dose since additional radioactive decay occurs after 30 years. In 100-year SAFSTOR, the occupational dose rates have decayed to about 30% of DECON and the costs, although increased by 30% over the 100-year period are still reasonable when evaluated against the reduced occupational dose.

ENTOMB is indicated as the least appropriate option. When the cost of surveillance in perpetuity is considered for the high-level waste repository that would in effect be created, this becomes the most costly decommissioning alternative. The savings in decommissioning dose that ENTOMB might offer over DECON could equally be saved using the 100-year SAFSTOR alternative.

0.8 SMALL MIXED OXIDE FUEL FABRICATION PLANT

This section is based primarily on a detailed study (4) of the decommissioning of a small mixed oxide fuel fabrication plant. A small mixed oxide (MOX) fuel fabrication plant is a manufacturing facility designed and constructed for the production of $(U\text{-}Pu)O_2$ pellets and incorporation of these pellets into clad fuel rods. The plant also has facilities for the recovery of plutonium from unirradiated scrap materials.

0.8.1 DESCRIPTION OF THE REFERENCE MOX FUEL FABRICATION PLANT

The reference plant is assumed to have operated for 10 years at a production rate of 2 MT of heavy metals per year. The feed to the plant can be either the oxide powders or nitrate solutions of plutonium and uranium. The plant operation is assumed to involve either mechanical blending of the oxide powders or coprecipitation of the solutions, using ammonia. The plant consists of a single building with a floor space of 2400 m^2 that also contains offices, laboratories, and maintenance shops. Auxiliary facilities are a cooling tower, an electrical substation, effluent storage, and a gas supply. Processes include solvent extraction, ion exchange, and oxalate precipitation for recovery of dirty scrap, and a two-stage liquid waste evaporation system followed by concreting of liquid wastes. The plant uses small, criticality safe vessels located in numerous glove boxes distributed throughout nine rooms. Operation of most steps is on a batch basis.

0.8.2 MOX DECOMMISSIONING EXPERIENCE

No direct experience exists in the decommissioning of licensed MOX fuel fabrication facilities because existing plants, which are not now operating, are being held in a standby or storage status. However, several government-owned plutonium fabrication facilities have been decontaminated, their usable source and special nuclear material recovered, and unusuable containers and processing equipment discarded as radioactive waste. In all cases, the buildings still stand and contain radioactive contamination above unrestricted levels. Some are closed and sealed but others have been converted to new, related facilities involving the use of radioactive materials.

0.8.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered and discussed here are DECON, SAFSTOR (custodial), and ENTOMB.

A special consideration for decommissioning MOX plants is the half-lives of the radionuclides present in the facility. The radionuclides processed in a MOX plant are received from a reprocessing plant, and include plutonium and uranium and their decay products, but not fission products. There are several isotopes of these actinides, and the radioactivity of these isotopes is very high particularly that of the plutonium. These isotopes have such long half-lives that it is apparent that deferred decontamination for 10 or even 100 years would not result in reduced radiation doses to decommissioning personnel and, therefore, SAFSTOR would not appear to be a reasonable alternative without some other justification.

0.8.3.1 DECON

DECON results in the release of the site and any remaining structures for unrestricted use as early as the 5 years estimated for decommissioning after the end of facility operation.

0.8.3.2 SAFSTOR

Generally, the primary advantage of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However, for the reasons given in Section 0.8.3, this is not the case for MOX plants. There appears to be little justification of the use of SAFSTOR for other reasons especially since its cost is higher than DECON.

0.8.3.3 ENTOMB

ENTOMB would involve the encasement in concrete of heavily contaminated rooms within the reference MOX facility until the radioactivity levels decayed to levels permitting unrestricted access to the facility. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radionuclides present. ENTOMB does not appear to be a viable alternative. The MOX plant will still contain 23 kg of plutonium estimated to remain in the process building following final inventory cleanout at shutdown, including ^{239}Pu with a half-life of 24,390 years and the entombed structure would, in effect, become a new surface waste disposal site. This would be an undesirable situation in that it would be contributing to the problems associated with an increased number of waste disposal sites.

0.8.3.4 Summary of Radiation Safety and Decommissioning Costs

Each of the decommissioning alternatives has associated with it unavoidable radiation exposures and costs. None of these is appreciably reduced with time.

0.8.3.4.1 Radiation Safety

In the DECON alternative, the radiation dose to occupational workers is 76 man-rem, and to the public it is 4 man-rem. Doses from transportation of wastes accounts for 6 and 1.5 man-rem of the respective dose totals.

In the SAFSTOR alternative, the total radiation dose to occupational workers for 10 and 30 years of safe storage are 165 and 307 man-rem respectively, with the public dose being the same as for the DECON alternative.

In the ENTOMB alternative, the occupational radiation dose is 10 man-rem and the public dose is 0.25 man-rem.

0.8.3.4.2 Decommissioning Costs

For DECON, the decommissioning costs are estimated to be $7.8 million. For custodial SAFSTOR, the total decommissioning cost is estimated to be $16.3 million and $28 million for 10-year and 30-year SAFSTOR, respectively. These SAFSTOR costs include $3.5 million for preparation for safe storage, $0.54 million per year for continuing care, and $7.3 million for deferred decontamination. A present value analysis of decommissioning costs indicates a disincentive to defer decontamination for the reference case indicated, primarily because of the high cost of continuing care relative to DECON costs and the high cost of deferred decontamination due to the long half-lives of the radionuclides involved.

0.8.4 ENVIRONMENTAL CONSEQUENCES

0.8.4.1 Waste

A major environmental consequence of decommissioning is the commitment of land area to the disposal of radioactive waste. PNL made the estimates shown in Table 0.8-1 of the waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. The volume for ENTOMB does not include the volume of the entombing structure or the wastes entombed within it. The entombing structure is effectively a new shallow radioactive waste burial ground.

TABLE 0.8-1 Burial Volume of Radioactive Waste and Rubble Resulting from Decommissioning a Reference MOX Plant(m^3)

Disposition of Waste	DECON	SAFSTOR (Custodial)		ENTOMB
		10 Years	30 Years	
Deep Geologic Disposal	164	205[(a)]	205[(a)]	21
Shallow Land Burial	267	267	267	5
Total	431	472	472	26[(b)]

[(a)] Includes 52 m^3 of waste from preparation for safe storage.

[(b)] Does not include volume of entombing structure or entombed waste.

If shallow land burial of radioactive waste in standard trenches is assumed, then a burial volume of 267 m^3 of radioactive waste can be accommodated in less than 0.02 acres. An additional 164 m^3 would be required in a high-level waste repository for the DECON mode.

0.8.4.2 Nonradiological Safety

Two potential nonradiological safety considerations are recognized. These are releases of chemicals used to decontaminate the plant and accidents in transporting materials to and from the plant. Transportation accidents are generally of low risk and, with appropriate considerations, chemical risks are also low.

0.8.4.3 Socioeconomic Effects

An immediately felt non-decommissioning effect of closing a MOX plant will be the loss of employment. Decommissioning will mitigate some of this effect for a short time.

0.8.4.4 Noise and Aesthetics

Noise levels will not be significant except for the ENTOMB alternatives. In ENTOMB, this will only be for a short period of time.

Aesthetic effects will not likely be a result of the decommissioning process itself, but will rather depend on the final disposition of the building and site.

0.8.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES (See Table 0.0-1 and 0.0-2)

Based on the radiation doses and decommissioning costs of each of the alternatives discussed above, DECON would seem to be the most advantageous alternative.

0.9 LOW-LEVEL WASTE BURIAL GROUND

Development of an EIS in support of regulations concerning the disposal of low-level waste along with accompanying regulatory activity for 10 CFR Part 61 is currently in progress. Additional details are given in the Federal Register Notice, 45 Fed. Reg. 13104 (1980).

0.10 URANIUM HEXAFLUORIDE CONVERSION PLANT

The function of a uranium hexafluoride (UF_6) conversion plant is to convert uranium concentrates, received from various uranium mills, to the purified uranium hexafluoride that is used as the feed material for the gaseous diffusion enrichment of ^{235}U. Currently there are five conversion plants in operation in the United States.

The plant described here is a reference plant that is assumed to have processed 10,000 metric tons (MT) per year of natural uranium and to have been in operation for about 30 years. A detailed report on the decommissioning of a UF_6 plant is planned for issuance in fiscal year 1982.

0.10.1 URANIUM HEXAFLUORIDE CONVERSION PLANT DESCRIPTION

0.10.1.1 Plant and Process Description

The plant consists of three buildings containing approximately 120,000 ft^2 of floor area. The buildings are of normal industrial construction, with heavy concrete floors to support equipment. In addition, there are a series of retention ponds for sanitary waste and process raffinates. The plant is designed to receive U_3O_8 or yellowcake in 208-liter (55-gallon) drums from various uranium mills located in the western United States and to convert the feed stock to uranium hexafluoride (UF_6). Two processes are in use today, which differ only in the method of purification.

The plant equipment, fabricated mostly of monel, is mainly a series of fluidized bed chemical reactors with intermediate vessels, such as storage bins, air classifiers, product filters, cold traps, and air effluent purification systems. The plant facility has pond areas for liquid effluents and a burial area for disposal of defunct equipment.

The purified UF_6 is placed in cylinders for storage and future shipment to one of the Department of Energy's enrichment plants.

0.10.1.2 Residual Radioactivity Estimates

The reference UF_6 plant processes 10,000 metric tons of natural uranium per year in the form of ore concentrate (yellowcake) produced by domestic uranium mills. The radionuclides of primary concern are natural uranium, ^{226}Ra, ^{230}Th, ^{234}Th, ^{234m}Pa, and ^{222}Rn. Natural uranium is the most abundant radionuclide present. The predominant health and safety consideration is not radiological, but rather the effect that heavy metal (uranium) chemical toxicity has on the human kidney.

0.10.2 URANIUM HEXAFLUORIDE CONVERSION PLANT DECOMMISSIONING EXPERIENCE

DOE has terminated UF_6 conversion at the Oak Ridge Enrichment Plant and at the Mallinckrodt Chemical Company Plant at Welden Springs, Missouri. The Welden Springs Plant is currently undergoing decommissioning, and the knowledge gained from this experience will be useful in the planning and decommissioning of similar plants. The status of decommissioning of the Oak Ridge Plant is not known at this time; however, a report on the decommissioning effort would appear to be beneficial for future commercial efforts.

0.10.3 DECOMMISSIONING ALTERNATIVES

The commissioning alternatives considered and discussed are DECON, SAFSTOR, and ENTOMB.

Special considerations involved in decommissioning the reference UF_6 plant include the following general assumptions:

1. natural uranium and its radioactive daughters are the only radioactive materials handled at the plant,

2. uranium spills that occur during the life of the plant, both inside and outside, are cleaned up immediately, and

3. safety reasons dictate that the maximum amount of uranium be removed from the plant prior to decommissioning.

Because of the low specific activity of uranium, radiation exposures of the public and the workers are negligible, and therefore are not significant in the choice of a decommissioning alternative. Thus, the owner can choose the most economical alternative for decommissioning with NRC concurrence. The most practical choice of decommissioning alternatives based on economics, appears to be basically only one: DECON.

0.10.3.1 DECON

For DECON, the end result is the release of the site and any remaining structures for unrestricted use as early as the 1-year estimated for decommissioning after the end of facility operation.

DECON costs are estimated to be $2.3 million and the occupational radiation dose is estimated to be 1 man-rem. Radiation dose to the public would be negligible.

0.10.3.2 SAFSTOR

Generally, the primary advantage of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However, for the reasons given in 0.10.3, this is not the case for UF_6 plants.

Continuing care would cost approximately $45,000 per year. A safe storage period of 10 years would result in total SAFSTOR costs of $2.8 million, which is larger than for DECON. This would take place with no increase or decrease in total radiation dose to the public or workers.

0.10.3.3 ENTOMB

Because the radiation levels from the trace amount of natural uranium in the equipment and buildings are nearly zero and because the process buildings are not suitable for ENTOMB, this is a very expensive and unnecessary decommissioning alternative and is not considered a viable option.

0.10.3.4 Site Decommissioning

No site decommissioning other than a radiation survey is expected to be necessary since it is assumed that each spill will be cleaned up immediately. However, the removal of possible onsite buried materials is expected to be a minor effort compared to the rest of the decommissioning.

0.10.4 ENVIRONMENTAL CONSEQUENCES

The environmental consequences of decommissioning a UF_6 conversion plant are small. The largest environmental impact is postulated to be the use of about 0.2 hectare (0.5 acre) of irretrievable land for shallow-land burial and the consumption of materials (gasoline, wood, metal tools, etc.) during the decommissioning activities.

0.10.4.1 Industrial Safety Consequences

The lost-time injuries and fatalities for all of the decommissioning alternatives are small.

0.10.4.2 Waste Disposal

The volume of low-level waste to be disposed of is estimated on the basis that all process equipment is discarded. The volume estimated, 570 m^3, is considered to be a maximum that requires about 0.2 hectare (0.5 acre) of a shallow-land burial site.

0.10.4.3 Additional Effects of Decommissioning

The socio-economic impacts are mainly from the shutdown (not decommissioning) of the facility and associated loss of about 100 jobs.

0.10.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES (See Tables 0.0-1 and 0.0-2)

ENTOMB is not considered a viable option. Of the two remaining alternatives, DECON and SAFSTOR, DECON appears to be the more advantageous option. This is because the radiation doses are negligible for either alternative, while DECON has low costs and results in release of the facility for unrestricted use in a fairly short time period.

0.11 URANIUM FUEL FABRICATION PLANT

A uranium fuel fabrication plant (U-fab plant) is a facility in which enriched uranium, received as uranium hexafluoride (UF_6), is converted to UO_2 and formed into fuel pellets that are inserted into fuel rods. These fuel rods are, in turn, assembled into fuel bundles. This is sometimes done in two stages at two different facilities. The reference facility considered here performs the whole operation. In this section, we have used information prepared for the study on the technology, safety and costs of decommissioning a reference U-fab plant which was conducted by PNL for the NRC.

0.11.1 U-FAB PLANT DESCRIPTION

The reference U-fab plant is assumed to have operated for 40 years, processing an average of 1000 MT of uranium per year. Production consists of three general kinds of activities: conversion of slightly enriched UF_6 to UO_2; mechanical production of fuel pellets and assembly of fuel rods and bundles; and recovery of uranium from scrap, wastes, and off-standard pellets.

The building is a two-story, windowless structure of concrete and steel. Interior walls, typically of concrete block, divide the building into discrete operations areas that house each of the production steps. The plant is shut down and the final inventory cleanout has been performed. It is anticipated that there will be a total of about 270 kg of unrecovered uranium remaining in the plant at shutdown. This uranium has enrichments that range from 2% to less than 5% ^{235}U. There will be CaF_2 waste ponds which contain some enriched uranium and will require some decommissioning activity. Although CaF_2 has low solubility, the toxicity of inorganic fluorides in general suggests that these wastes may be a biological hazard.(6)

0.11.2 U-FAB PLANT DECOMMISSIONING EXPERIENCE

Several U-fab plants have ceased operation and are in various stages of decommissioning. Perhaps the best experience in decommissioning a low-level enriched U-fab plant was with a General Electric U-fab Plant in San Jose, California.

0.11.3 DECOMMISSIONING ALTERNATIVES

The decommission alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB.

0.11.3.1 DECON

For DECON, the end result is the release of the site and any remaining structures for unrestricted use as early as the 9 months estimated for decommissioning after the end of facility operation.

DECON of a U-fab plant presents few problems except for decontamination of the waste ponds and other areas where the soil is contaminated. Wastes in the nitrate ponds will have been removed, shipped to another plant, and reprocessed; but the calcium fluoride waste may have to be removed and shipped to a low-level waste burial ground. It is also possible that the CaF_2 waste may be removed and reprocessed at another plant to recover uranium. The CaF_2 would then be disposed of by the new owner. The non-radioactive chemical wastes will be sent to a chemical waste burial ground.

The occupational radiation dose for the DECON alternative is estimated as 18.6 man-rem, and the public dose as 0.6 man-rem. Transportation of wastes contributes 2.6 and 0.5 man-rem to these respective radiation dose totals.

0.11.3.2 SAFSTOR (Custodial)

Generally, the primary advantage of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However, this is not necessarily the case for U-fab plants due to the low radioactivity levels and long half-lives of the radionuclides present in the plant.

For the SAFSTOR alternative, the occupational radiation dose for 10- and 30-year safe storage is estimated to be 30 and 62 man-rem. The public dose for the 10- and 30-year safe storage period is estimated as 0.7 and 0.8 man-rem. The amount which transportation of wastes contributes to doses is the same as for DECON

0.11.3.3 ENTOMB

ENTOMB is not a viable decommissioning alternative due to the long half-lives of the radionuclides present and the low radiation doses associated with DECON.

0.11.3.4 Summary of Radiation Safety and Decommissioning Costs

0.11.3.4.1 Radiation Safety

Residual radioactivity following inventory removal at a U-fab plant will be confined mainly to the interior parts of equipment and the ventilation system. The CaF_2 waste, containing some uranium, may have to be reprocessed or sent to a low-level waste burial ground. If it was packaged and shipped to a low-level waste burial ground for disposal, this would result in additional occupational and public radiation doses of 20 and 0.4 man-rem respectively.

The radioactivity in a U-fab plant is mostly due to ^{235}U and ^{234}U. External dose to decommissioning workers will be at plant background, which is about 1 mrem/hr. Because of the long half-life of ^{235}U, (approximately

7×10^8 years) this background will not be decreased appreciably by placing the plant in custodial safe storage for a time before deferred decontamination.

0.11.3.4.2 Decommissioning Costs

For DECON, the decommissioning costs are estimated to be \$3.5 million. For custodial SAFSTOR, the total decommissioning cost is estimated to be \$8.9 million and \$17.5 million for 10-year and 30-year SAFSTOR, respectively. These SAFSTOR costs include \$0.78 million for preparation for safe storage, \$0.43 million per year for continuing care, and \$3.8 million for deferred decontamination. A present value analysis of decommissioning costs indicates a disincentive to defer decontamination for the reference case indicated, primarily because of the high cost of continuing care relative to DECON costs and the high cost of deferred decontamination due to the long half-lives of the radionuclides involved. Therefore, from a cost standpoint, it is probably to an operator's advantage to choose the DECON alternative and convert the building to other uses.

The CaF_2 waste will potentially be disposed of in a low-level waste burial ground, and removal, packaging, shipment, and burial would cost an additional \$7 million.

0.11.4 ENVIRONMENTAL CONSEQUENCES

Because radiological effects are quite small, the potential nonradiological effects will have the greater impact on the environment.

0.11.4.1 Nonradiological Safety

The area of greatest concern for the welfare of decommissioning workers is the calcium fluoride lagoons and storage pits. The very caustic nature of CaF_2 makes it necessary to protect the workers from contacting it on their skin and breathing the dust.

0.11.4.2 Commitment of Resources

The largest commitment of resources will be for space in chemical and low-level waste burial grounds. The burial volume of contaminated equipment, building components, and concrete is 1100 m^3, the burial volume of CaF_2 waste would be 29,600 m^3 (accounts for almost 3 acres of burial ground), and the burial volume of other chemical waste are 5300 m^3.

0.11.4.3 Socioeconomic Effects

Decommissioning will mitigate some socioeconomic effects caused by termination of plant operation.

0.11.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES (See Tables 0.0-1 and 0.0-2)

Based on the radiation doses and decommissioning costs of each of the alternatives discussed above, DECON appears to be a more advantageous option.

0.12 INDEPENDENT SPENT FUEL STORAGE INSTALLATION

The purpose of an independent spent fuel storage installation (ISFSI) is to store irradiated fuel assemblies from nuclear power reactors until an adequate disposal method is adopted, such as fuel reprocessing or disposal as high-level wastes. This facility, which would be built away from the reactors, is presently in the conceptual design stage and would have a storage capacity of 5000 MT of spent fuel. No facility of this size has been designed or licensed. PNL is scheduled to complete a study on decommissioning of ISFSI's by 1982.

0.12.1 ISFSI DESCRIPTION

The ISFSI is designed to receive, store, and prepare for shipment irradiated fuel from light-water power reactors. The spent fuel assemblies are stored at the reactors for at least one year and then shipped to the ISFSI in shielded casks by either truck or rail transport. The fuel assemblies are then unloaded from the casks under water and placed in storage racks in the fuel storage pool until their future disposition is determined.

The fuel storage pool has reinforced concrete walls and floors that are lined with stainless steel. It is filled with water to a depth of about 9 m (30 ft). The water, which provides both shielding and cooling for the radioactive fuel assemblies, is circulated through heat exchangers to remove decay heat and then through filters and ion exchange beds as necessary to remove both particulate and dissolved radionuclides.

The major portions of the ISFSI are arranged as a total structural complex, as shown in Figure 12.1-1. The combined structures include an area about 210 m (700 ft) long and 150 m (500 ft) wide. The storage area is composed of one or more fuel pools, with a total capacity of 5,000 MT of irradiated fuel. The area occupied by the buildings containing radioactive material is about 3.2 hectares (8 acres). The whole complex occupies about 20 hectares (50 acres) enclosed by one or more security fences.

0.12.1.1 Estimates of Radioactivity Levels at the time of ISFSI Shutdown

The sources of radioactivity in the pool water are activation products and fission products. The activation products are crud deposits and corrosion films on the fuel assembly surfaces. The fission products come from fuel assemblies with rods that failed while in service in the reactor or from intact fuel assemblies that adsorbed circulating fission products. Despite the similarities in design, there are substantial differences in the inventory of radionuclides at reactor pools and ISFSI pools due to the different operational considerations.

0.12.2 ISFSI DECOMMISSIONING EXPERIENCE

To date, there has been no experience in the complete decontamination of a commercial ISFSI. However, in November 1971, Nuclear Fuel Services (in West Valley, New York) cleaned a fuel storage pool in which 150 failed N-reactor fuel elements had been stored from 1968 to 1970 which provides some background in methods and procedures which might be used in ISFSI pool decontamination.

0.12.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB.

The decommissioning of the ISFSI could be performed using any of the alternatives described below. However, in view of the relatively low radiation fields to be encountered by the decommissioning crew, it appears that DECON would be the most viable option.

0.12.3.1 DECON

The first step of each of the decommissioning alternatives is the chemical decontamination of the equipment. In the case of DECON, an extensive flushing procedure would be used to remove the maximum amount of contamination, thus reducing occupational exposure to a minimum.

The estimated occupational radiation dose from DECON is 72 man-rem. The public radiation dose is estimated to be negligible. The cost of DECON is estimated to be $4.6 million.

0.12.3.2 SAFSTOR

SAFSTOR requires that the residual radioactivity be contained such that there is reasonable assurance that the public cannot be exposed inadvertently during the continuing care period. In the ISFSI the fuel pools are surrounded by a relatively lightly constructed building (i.e., mostly steel frame members covered with steel or transite siding and roof). Sealing this building off to prevent any type of forced entry is difficult. However, from a radioactivity exposure viewpoint, the dose rates in the building are very low (1 to 10 mR/hour on the average), and it would take 4 days of close contact with the contaminated material to obtain a dose of 1 rem. Thus, it is possible that the building structure can afford adequate protection for such a low exposure rate.

The occupational radiation dose from SAFSTOR is 72 man-rem plus 0.5 man-rem per year of safe storage. Public radiation dose is expected to be negligible. SAFSTOR does not reduce the doses below DECON due to the long half-lives of the remaining radionuclies. The cost estimates are $2.2 million for safe storage preparation, $46,000 per year of continuing care, and $3.7 million for deferred decontamination.

0.12.3.3 ENTOMB

ENTOMB uses a structure to hold or confine the radioactivity until such time as it has decayed to levels permitting unrestricted facility use. Most radionuclides of concern will have all decayed during the 15- to 40-year operating life of the ISFSI, with the exception of small amounts of ^{60}Co, ^{90}Sr, and ^{137}Cs. Therefore, it appears at first that ENTOMB of the fuel pool areas might be a viable option because within 60 years most of the radioactivity would have decayed away except for the small amounts of ^{90}Sr and ^{137}Cs. However, the ISFSI may be contaminated with ^{137}Cs to too great an extent, and certification that the levels are low enough to decay to unrestricted levels within the expected period of structural integrity of the entombment would be very difficult. If the entombment were performed by placing all contaminated equipment in the bottom of the storage pool and covering it with 1.8 m (6 ft) or more of concrete, the structural integrity of the building would be expected to last for at least 200 to 300 years. However, this is longer than what can be reasonably assured for continued administrative controls.

Occupational radiation exposures for ENTOMB are estimated to be 15 man-rem. This reduction compared to DECON is considered to be of marginal significance to health and safety. Public exposure would be negligible. The estimated cost of ENTOMB is about $3.3 million, with $442,000 of this cost for concrete. Substantial costs would be incurred for surveillance and maintenance of $46,000 per year. For the 200-300 years this would amount to $8 to $12 million. However, surveillance costs could continue in perpetuity.

0.12.4 ENVIRONMENTAL CONSEQUENCES

0.12.4.1 Industrial Safety

Industrial safety problems caused by decommissioning are very minor.

0.12.4.2 Waste Disposal

The volume of low-level waste to be transported to a low-level burial site would vary from nearly zero for ENTOMB to about 1,020 m^3 (11,000 ft^3) for DECON. ENTOMB, in effect, would create a low-level waste burial site out of the ISFSI. SAFSTOR could result in slightly more material than for DECON.

The 1,020 m^3 (11,000 ft^3) of waste requiring burial would represent the use of what could be irretrievable land (approximately 1 acre). This is the largest negative impact in the ISFSI decommissioning process. This loss of land use, however, is more than balanced by the return of the ISFSI site (50 acres) for the public use.

0.12.4.3 Additional Effects

In summary, all alternatives appear to have only a small negative environmental impact. This impact is from the burial of radioactive waste, the use of expendable supplies, and the small amount of noise from operation of heavy equipment during decommissioning. The return of the 20-hectare (50-acre) site for the public use is a positive environmental impact. The socioeconomic impacts are mainly from the shutdown (not decommissioning) of the storage facility, which would reduce the income of the community and region because of the loss of about 30 to 40 jobs.

0.12.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

DECON appears to be a more viable option than SAFSTOR. Since all of the site would be free of contamination, it would be possible to release it for public use. ENTOMB appears to be the least viable option. Aside from contributing to the problems associated with an increased number of radioactive waste burial sites, the minimum required surveillance costs are approximately \$6 to \$8 million which, when combined with the \$3.25 million estimated for decontamination, make this option the most costly.

0.13 NUCLEAR ENERGY CENTER

PNL is presently preparing a study of the technology, safety, and costs of decommissioning a nuclear energy center. Among the subjects explored in the PNL study will be the use of interim storage of waste at the nuclear energy center. In particular, the possibility of storage of high activity waste until its major short-lived isotopes have significantly decayed (e.g., ^{60}Co) would be a serious consideration. Moreover, a modular construction concept, whereby highly radioactive components such as the pressure vessel could be removed intact (and temporarily stored onsite to allow for dose reduction through decay) will also be explored. Through such modular construction approaches, facilities could be more easily decommissioned or refurbished.

It is the purpose of this section to investigate on a preliminary basis whether significant decommissioning differences might exist between a single reactor on a site and one at a multiple reactor facility and whether this could have an effect on regulatory considerations. Accordingly, an attempt was made to exaggerate any possible differences that might occur in the decommissioning activities through the choice of a very large nuclear energy center which, over its operational lifetime, consists of the staged construction of 40 1200-MWe reactors, 2 independent spent fuel storage installations (ISFSI), and [illegible] nuclear waste disposal facilities adequate for the lifetime of the nuclear energy center. Preliminary results of the PNL study indicate that the conclusions reached in the more restrictive analysis presented in this section do not differ significantly from the more general ones presented in earlier chapters for single reactors.

0.13.1 NUCLEAR ENERGY CENTER DESCRIPTION

No commercial nuclear energy center exists today, so it is necessary to develop a reasonable model. Forty 1200-MWe reactors could be constructed on a single site at 2-year intervals without unduly disrupting the socioeconomic structure of the surrounding area. No more than five reactors would be under construction at any one time, and no more than two need be undergoing active decommissioning procedures at one time. Also, no more than 20 reactors (24,000 MWe) would be operating at any one time, assuming an operating lifetime of 40 years. Two ISFSIs would be required, and could be decommissioned at different times. We assume, for comparative purposes, that burial facilities for all nuclear wastes generated at the center would be available onsite and that the facilities would be final repositories.

0.13.1.1 Site Description

A land area of 97 km^2 (37.5 square miles, or 24,000 acres) would suffice for a nuclear energy center that contains space for the reactors themselves. Approximately 24.3 km^2 additional space (9.4 square miles, or 6,000 acres) would easily allow adequate space for nuclear waste burial, for two ISFSIs, and for later addition of other fuel cycle facilities, if required. A river flows through the site with an aveage flow rate of 1420 m^3/sec (50,000 ft^3/sec) and the site is suitable for high- and low-level waste disposal.

0.13.1.2 Facility Description

The site would contain forty 1200-MWe PWRs, two 5000-metric ton (MT) ISFSIs, and facilities suitable for the disposal of 3.2 million m^3 (112 million ft^3) of radioactive waste. The reactors could be PWRs or a combination of BWRs and PWRs. We assume PWRs here for simplicity of the analysis.

0.13.1.3 Construction and Operation Sequences

Ease of decommissioning depends on the timing of construction and operation of the nuclear energy center. Section 0.13.1 describes the sequence of these operations.

0.13.2 NUCLEAR ENERGY CENTER DECOMMISSIONING EXPERIENCE

No commercial energy centers have been constructed. Studies are underway, however, on decommissioning military nuclear sites that contain several reactors, fuel fabrication facilities, reprocessing facilities, and waste burial grounds.

0.13.3 DECOMMISSIONING ALTERNATIVES

The nuclear energy center offers more decommissioning options than do facilities located on dispersed sites, both because the facilities could be efficiently decommissioned one after another and because the facilities are located on a site that is presumably to be controlled for several hundred years.

The alternatives considered here are: DECON, SAFSTOR, and ENTOMB.

0.13.3.1 DECON

For DECON, each reactor could be decontaminated to radioactivity levels permitting release of the facility for unrestricted access at the end of its 40-year operating lifetime. All 40 reactors would undergo DECON in sequence and, assuming construction takes 10 years and DECON 4 years, the first reactor would complete DECON by the end of the 54th year and the 40th reactor would complete DECON by the end of the 132nd year (see Figure 13.1-1). Because the waste disposal facility is located onsite, occupational radiation dose from transportation activities would be reduced, and public radiation dose from transportation activities would be eliminated. Thus, the public radiation dose from all reactor activities would be essentially zero, and occupational radiation dose per reactor would be reduced from 1183 man-rem to 1091 man-rem. Occupational and public radiation doses from DECON of the ISFSIs would not change because the occupational and public radiation doses from transportation activities are already negligible. In calculating the radiation dose from decontaminating a nuclear energy center, no credit was taken for efficiencies that might develop from repetitive decontamination. These efficiencies could easily reduce the radiation dose from decontaminating the newer facilities.

The cost per facility for DECON of a nuclear energy center is reduced below the cost for DECON of equivalent facilities on dispersed sites because costs of transportation and planning are reduced. The cost of DECON for each PWR is reduced from $33.3 million at dispersed sites to $29.2 million at a nuclear energy center, and the cost of DECON for each ISFSI is reduced from $4.6 million to $4.3 million.

0.13.3.2 SAFSTOR

Occupational radiation dose from reactor decommissioning would be reduced because of reduced transportation distance to waste disposal sites. The total dose reduction would be from 329 man-rem for a single site to 318 man-rem for a nuclear energy center for a 30-year SAFSTOR. Public radiation dose from reactor decommissioning would be reduced from 3 man-rem to essentially zero for a 30-year SAFSTOR because the waste transportation activities all take place onsite. There would be no reduction in either public or occupational radiation doses from decommissioning the ISFSIs, because transportation related doses are already essentially zero.

Costs of 30-year SAFSTOR for a PWR would be reduced from $42.8 million for a single site to $37.4 million for a nuclear energy center because of planning, transportation, and surveillance cost savings. Similar savings would reduce the cost of 30-year SAFSTOR of the ISFSI from $7.3 million to $7.0 million.

0.13.3.3 ENTOMB

ENTOMB is a relatively unattractive decommissioning alternative for a nuclear energy center. While the initial cost of entombment per reactor may be only one-half that of the total cost of 30-year SAFSTOR, the radiation dose may be more than twice as much. Also, surveillance and maintenance costs of $20,000 per year would continue in perpetuity, since as the entombed structure could contain very long-lived radionuclides.

Although two ENTOMB alternatives are possible, only the case of reactor internals removed (and disposed of onsite) offers the possibility of radionuclides in the facility decaying to levels permitting unrestricted use of the facility within a reasonable time, i.e., the order of 100 years. The total occupational radiation dose per reactor with internals included is 900 man-rem. The total occupational radiation dose per reactor with internals removed is 1,000 man-rem. Radiation dose to the public would be reduced to near zero in either case because transportation of radioactive wastes is confined to the site. The radiation dose to workers (15 man-rem) and to the public (negligible) from decommissioning the ISFSIs would not change.

The cost of ENTOMB with internals included would be reduced from $21 million for a single site to $18.9 million, for a nuclear energy center, and the cost of ENTOMB with internals removed would be reduced from $27 million to $25.1 million. The cost of continuing surveillance during ENTOMB would be reduced from $40,000 per year to $20,000 per year. The cost of ISFSI ENTOMB would be reduced from $3.25 million to $3.05 million. The cost for ISFSI surveillance and maintenance during ENTOMB which could continue in perpetuity ($46,000 per year) may be somewhat reduced while other facilities onsite are also under surveillance. ENTOMB (without internals) for reactors has some viability because of long-term continued presence onsite of surveillance crews. However, adequate characterization of radionuclide content for license termination may be difficult.

0.13.4 ENVIRONMENTAL CONSEQUENCES

Because handling of all radioactive materials is carried on within the boundaries of the nuclear energy center, radiological impacts on the public will be very less than for a single reactor site.

Radiological impacts on transportation workers will also be less because transportation of wastes is confined to the center.

Waste disposal will include the dedication of approximately 1 km^2 (250 acres) of radioactive waste burial grounds (20% of which is estimated as due to decommissioning waste). It is assumed that appropriate control of inventory and site will allow for unrestricted release in several hundred years for shallow-land burial.

Decommissioning will mitigate some socioeconomic impacts due to termination of reactor operations.

0.13.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

For a reactor at a nuclear energy center, 30-year SAFSTOR is probably a more acceptable alternative than for a single reactor facility. DECON and ENTOMB (with internals removed) are also possible alternatives at higher radiation dose and lower cost: the more likely alternative being DECON. Surveillance would, of course, have to be maintained in the case of ENTOMB.

0.14 NON-FUEL-CYCLE NUCLEAR FACILITIES

Non-fuel-cycle facilities are those facilities which handle byproduct, source, or special nuclear material but which are not involved in the production of power. There are almost 20,000 non-fuel-cycle facilities in the United States at which such materials are handled under specific licenses of the NRC and the agreement states.

These facilities represent a wide variety of applications in industry, medicine and research. PNL is presently developing a study of the technology, safety, and costs of decommissioning non-fuel-cycle facilities. Preliminary evaluation of some selected facilities have been made for the purpose of supporting this EIS. These selected facilities represent those which may require significant decommissioning efforts; they are a very small portion of the 16,000 non-fuel-cycle facilities, most of which do not present significant decommissioning problems.

0.14.1 FACILITIES DESCRIPTION

0.14.1.1 Sealed Source Manufacturer

Sealed sources are manufactured for such uses as reference standards, moisture probes, quality control instruments, therapy units, and smoke detectors. For the most part these are low-activity long half-life sources although some contain large quantities of activity (^{60}Co therapy units). Most are manufactured in manual operations. Contaminated equipment includes such things as hoods, glove boxes or cells, and ducts and filters. Some radioactive wastes are stored onsite in drums until decayed or until disposal at a low-level waste burial facility.

0.14.1.2 Radiochemical and Radiopharmaceutical Manufacturers

These facilities are similar to that of sealed source manufacturers in that operations are carried out in ventilated enclosures. Chemical manufacturing requires more extensive and complicated laboratory equipment, but the physical facility is basically the same.

0.14.1.3 Ore Processors

There are a few processing facilities in the United States that extract metals such as tantalum and niobium from tin slag containing uranium and thorium and that also store the tailings from their processing on site. There is no significant contamination of the facilities themselves but the large volumes of the tailings do present a significant decommissioning problem.

0.14.1.4 Broad Research and Development Program Facility

R&D facilities using nuclear materials cover an extremely broad range of activities. A large university with medical program is considered as a representative facility. The reference facility contains about 400 laboratories and health treatment areas where radioisotopes are or have been used. For the most part there is little decommissioning effort required because of short half-lives or low activity of material used.

0.14.2 NON-FUEL-CYCLE MATERIALS FACILITIES DECOMMISSIONING EXPERIENCE

Decommissionings of non-fuel-cycle facilities have been many and varied, and a large number of these operations have had little cost or environmental impact. Because of their unique sizes, locations, and conditions, no two facilities had identical decommissioning problems or conditions. Documentation is fragmentary; however, the documentation that is readily available on the decommissioning of these facilities, as well as other general decommissioning experiences, provides useful information for practical generic considerations concerning non-fuel cycle decommissioning.

0.14.3 DECOMMISSIONING ALTERNATIVES

Decommissioning alternatives likely to be used for non-fuel-cycle materials facilities are discussed in the following subsections, first in general terms and then as applied specifically to certain types of facilities.

0.14.3.1 Decommissioning Alternatives for Non-Fuel-Cycle Facilities

Since there is such a large range in the type and size of facilities and operations licensed to handle radioactive materials, the level of effort required to decommission these facilities varies greatly. The necessary actions can vary from essentially administrative procedures (in addition to a final survey which could be similar to operational surveys) to a multi-million dollar effort. For a large number of materials facilities some variation or combination of alternatives will be the best choice. Alternatives for decommissioning considered and discussed here are: 1) DECON, 2) SAFSTOR, and 3) ENTOMB.

0.14.3.1.1 DECON

For many materials handling facilities, the most appropriate decommissioning alternative will be DECON, but with little need for dismantling procedures.

0.14.3.1.2 SAFSTOR

The simplest case of SAFSTOR would most likely occur if most or all of the radioactivity is derived from relatively short-lived nuclides that will decay to unrestricted levels in a short time. In this case, little action, in some cases just a survey, is expected to be required at the time of final decontamination.

Stabilization may be a mode of decommissioning considered for the slag remaining at ore processing facilities. At this time, the NRC has not determined whether this will be acceptable; but for the time being at least, its acceptability would be considered on a case-by-case basis. Stabilization of slag piles would be considered as preparation for safe storage and would require monitoring until final disposition.

0.14.3.1.3 ENTOMB

Because of the expense of construction and the low radioactivity level of most of the isotopes handled at non-fuel-cycle facilities, ENTOMB does not appear to be a viable alternative.

0.14.3.2 Decommissioning Alternatives for Sealed Source and Radiochemical Manufacturers

The alternatives considered for decommissioning these facilities are: DECON and SAFSTOR.

0.14.3.2.1 DECON

DECON is a logical alternative for facilities for the manufacture of sealed sources and radio-labeled chemicals. It is relatively uncomplicated, will eliminate need for continued monitoring, and will release the facility for other uses.

Some estimates have been made for some typical individual laboratories of the costs of DECON. They range from a few thousand dollars to over $14,000 for a gamma lab with a hot cell and overhead manipulators. These costs would have to be multiplied by the number of such laboratories in a given facility to estimate the overall cost for decommissioning the entire facility.

The total occupational dose in the DECON of a gamma laboratory with hot cell would be about 0.5 man-rem.

0.14.3.2.2 SAFSTOR

SAFSTOR is a reasonable alternative for decommissioning if the isotopes involved at a particular facility are short-lived and the facility has no other immediate planned usage. SAFSTOR may allow the radioactivity to decay to low enough levels that no further decontamination is required and that only a survey and administrative action is necessary for releasing the facility for unrestricted use.

0.14.3.3 Decommissioning Alternatives for Processor of Radioactive Ore

The milling of nonradioactive metals from ores containing uranium and thorium will contaminate the milling or handling equipment where the materials are retained by machinery. A simple survey and cleanup is the only decommissioning action necessary. As the materials are processed, all of the uranium and thorium remain with the sludge from the initial extraction, and the following decommissioning alternatives apply to the sludges: removal (DECON), and neutralization and stabilization for long-term care.

0.14.3.3.1 Removal (DECON)

A decommissioning alternative is removal of the sludge from the milling site and disposal of it at a low-level waste burial ground. Drawbacks are the great amount of materials that must be handled for the sake of a relatively small amount of radioactivity and the long distances that the material must be hauled. Disposal of 20 million pounds of sludge was estimated to cost about $2.9 million.

Exposures are similar to that for workers at uranium mill tailings piles. Respirators would be worn to reduce inhalation of particulates leaving ^{222} Rn as the major concern. Occupational doses would be about 1 man-rem/10^6 lb of sludge (approximately 20 man-rem for the 20 million pound pile considered). Dose to the population would be about 2×10^{-2} man-rem/10^6 pounds.

0.14.3.3.2 Neutralization and Stabilization

For the reference case this decommissioning alternative would involve: removing the roof, covering the pile with lime to neutralize residual acid, covering the entire structure with backfill, adding a clay cap, covering with top soil, and planting vegetation. This would have to be followed by some kind of long-term care. The viability of this option would have to be considered on a case-by-case basis. Stabilization would cost about $80,000 and would result in an occupational dose of 0.2 man-rem for the 20 million pound pile considered. Population doses were calculated to be extremely low.

0.14.3.4 Decommissioning Alternatives for a Broad Research and Development Program Facility

Decommissioning a large R&D facility is a piecemeal operation because of the many separate working areas involved, although, each is relatively uncomplicated. Preparation for decommissioning must include an exhaustive survey to discover isotopes such as ^{14}C which could be left over from experiments conducted several years previously. Decommissioning alternatives considered are: DECON and SAFSTOR.

0.14.3.4.1 DECON

A viable alternative for decommissioning an R&D laboratory is DECON. For many of the laboratories, this will not require discarding equipment. Most equipment can be decontaminated by washing. The greatest decommissioning cost is expected to be the survey. This will require 1 man-day of labor. There would be additional costs if disassembly of some equipment is required. The total occupational dose for the reference laboratory is on the order of 1 man-rem.

0.14.3.4.2 SAFSTOR

This alternative is likely for most R&D facilities since mostly short-lived isotopes are used. However, if a lab handled only ^{3}H or ^{14}C, DECON is a more viable alternative. If several isotopes have been used in the same facility it may be desirable to let short-lived ones decay before decontaminating. For SAFSTOR, the survey for monitoring decay is the most costly activity. Personnel exposure will be negligible.

0.14.4 ENVIRONMENTAL CONSEQUENCES

The effects of decommissioning on local work force and local economy are minor compared to the shutdown itself

The greatest terrestrial disturbance will come from decommissioning an ore processing facility, because of the large amount of material involved. The option of stabilizing the tailings will require a large amount of earthen fill, the obtaining of which will necessitate digging up another area. Both the stabilized site and the borrow area will likely require reclamation and monitoring to prevent problems of erosion and surface water sedimentation. Of great concern with these facilities will be the chemical toxicity from the processing chemicals and heavy metals in the tailings.

Both occupational and public exposure to radioactivity will be small.

0.14.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

A comparison of options is highly specific for each kind of materials facility. For most of the facilities that come under this designation, a removal of inventory will eliminate nearly all of the possibility of radiation exposure. The facilities discussed here are those perceived to have the greatest need for decommissioning action.

Based on the discussion above in this section, the most likely alternative for most materials facilities is DECON. Where short-lived isotopes have been used, SAFSTOR may be practical. ENTOMB is not practical for any of these facilities.

Stabilization with long-term care may be viable for the disposal of tailings from an ore processor, depending on site location. The disposition of radioactive ore tailings (other than stabilization) has limited possibilities. Removal of the tailings to a low-level waste burial ground will be expensive but is feasible. Reprocessing to remove the radioactive elements from the sludge lacks practicality, mainly because the volumes and rates of production are not attractive to commercial processors.

0.15 NRC POLICY CONSIDERATIONS

At the end of the useful life of a commercial nuclear facility, prompt NRC (or agreement state) termination of license is a desired objective. For such a facility, removal of the radioactivity to levels permitting unrestricted access to the facility (including site) through decommissioning is mandatory for full license termination. Present policy and regulatory guidance which addresses nuclear facility decommissioning is not specific enough to adequately effect this desired objective in a manner consistent with protection of the public health and safety. The NRC has currently underway a plan for reevaluation of its decommissioning policy on nuclear facilities.(10)

Decommissioning that occurs as a result of premature closure due to accidents may involve technical and cost considerations not yet completely evaluated. Studies to develop a complete data base on this subject will begin in fiscal year 1981, with a detailed report on decommissioning following a postulated accident, similar to the reports prepared for the facilities in this EIS, to be issued in fiscal year 1982. While the basic purpose and objective for decommissioning facilities involved in accidents would be the same as for routine decommissioning, some of the specific aspects of the technology, safety, and costs of decommissioning may differ. Nevertheless, in many instances, these specific aspects would have similarities between accident and routine decommissioning, in particular in areas such as decommissioning alternatives and timing, planning and facilitation, financial assurance, and residual radioactivity limits. It is not expected that major changes in the conclusions of this EIS will result from the technical studies on accident decommissioning, although, there may be some differences in specific criteria. These items will be considered upon completion of the studies initiated in 1981.

Based on the nearly completed data base results and on NRC staff considerations, taking account of the concerns of the States and public, and of the regulatory role NRC must provide in protecting public health and safety, the following conclusions appear evident:

(1) The technology for decommissioning nuclear facilities is well in hand. Decommissioning at the present time can be performed safely and at reasonable cost.

(2) Decommissioning of nuclear facilities is not an imminent health and safety problem. However, planning for decommissioning as an integral activity prior to commissioning is a critical item that can impact on health and safety as well as cost.

(3) Decommissioning of a nuclear facility generally has a positive environmental impact.

The major adverse environmental impact of decommissioning is the commitment of small amounts of land for waste burial in exchange for reuse of the facility for other nuclear or nonnuclear purposes.

0.15.1 MAJOR REGULATORY PARTICULARS

0.15.1.1 Decommissioning Alternatives and Timing

0.15.1.1.1 Decommissioning Alternatives

Decommissioning of a nuclear facility should have as its primary objective thorough decontamination of radioactivity resulting in unrestricted use of the facility at the earliest practical time. In certain situations, the potential for occupational exposure reduction resulting from radioactive decay would allow for the use of safe storage or entombment. An upper limit for the period of safe storage or entombment is about 100 years, which is consistent with EPA recommended policy on institutional control reliance for radioactivity confinement.

Categorization of decommissioning alternatives is broken into three major classifications which are referred to in this EIS by the pseudoacronyms DECON, SAFSTOR, and ENTOMB.

All of the decommissioning alternatives lead to unrestricted access to the facility. DECON results in this unrestricted access shortly after cessation of facility operations. SAFSTOR defers the release of the facility for unrestricted access until after a final decontamination following a period of safe storage. ENTOMB defers unrestricted access until radioactive decay reduces residual contamination to a suitable level while the facility is in a state of entombment. Based on EPA guidance, an upper limit of 100 years is the maximum allowable delay for affecting unrestricted facility access through decommissioning.

In summary, from the analysis of the technical data base, as discussed in earlier sections of the EIS, decommissioning can be accomplished safety and at modest cost shortly after cessation of facility operation, and, therefore, DECON would be considered the more preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR or ENTOMB Completing decommissioning and releasing the facility for unrestricted use eliminates the potential problems which may result from the increased number of sites used for the confinement of radioactively contaminated material, as well as eliminating potential health, safety, regulatory, and economic problems associated with maintaining the site. Delay in the completion of decommissioning, as in the case of SAFSTOR or ENTOMB, would be primarily for reasons of health and safety considerations, since it is recognized that with delay there may be reduction in occupational dose and radioactive waste volume for some facility types due to radioactive decay. Delay for such reduction would require additional justification since the amount of such reduction is of marginal significance in its effect on health and safety.

0.15.1.1.2 Timing

Timing of decommissioning is the length of time after facility shutdown that decommissioning activities should reasonably last before a license is terminated. The different facilities discussed in this EIS have different nuclides considered critical in the decommissioning of that specific facility. Based on the technical studies of the various nuclear facilities discussed in this report, this section categorizes permissible decommissioning alternatives for specific critical/abundant facility contaminant radionuclides. This is done by classification of alternatives in terms of three major characteristic critical/abundant radionuclide half-life time limits of 5, 30, and greater than 30 years.

If the critical/abundant radionuclide for a specific facility has a 5-year half-life, the decommissioning alternatives DECON, SAFSTOR, and ENTOMB would be permissible within appropriate constraints. If the critical/abundant radionuclide has a 30-year half-life, only DECON and SAFSTOR would be permissible. For facilities with critical/abundant radionuclide half-lives greater than 30 years, only DECON would be permissible.

0.15.1.2 Planning

0.15.1.2.1 Initial Plans

Planning for decommissioning is a critical item for ensuring that the decommissioning activity is accomplished in a safe, efficient, and timely manner. For the facilities considered in this report, the majority of the actual decommissioning will occur at termination of operation. It is necessary, however, to implement an initial decommissioning plan prior to commissioning of a nuclear facility to appropriately facilitate desired decommissioning objectives. Initial plans do not require the level of detail required for the final version. They must demonstrate, however, that certain aspects of decommissioning planning required prior to commmissioning and during facility operation are adequately addressed. The initial plan should describe: (1) the decommissioning alternative tentatively considered for use, and the cost estimate and method of assurance of funding for the decommissioning alternative, (2) consideration of facilitation of design and operations for improving health and safety during decommissioning, and (3) recordkeeping of relevant information.

0.15.1.2.2 Final Plans

Final decommissioning plans should contain much greater detail than initial plans. Such plans should be submitted in a timely way to the NRC for review and approval prior to the initiation of any decommissioning activity to avoid delay of decommissioning after facility shutdown. For a major power reactor such review and approval could take on the order of a year. Final plans should include: (1) a detailed description of the decommissioning alternative selected for use, including plans to protect health and safety, plans for waste disposal, and plans for a final termination survey, (2) detailed schedules, (3) administrative controls, (4) proposed specifications on controls and limits for procedures and equipment used, and (5) details of a training program for employees and contracts personnel.

0.15.1.3 Financial Assurance

The primary objective of the NRC with respect to decommissioning, is to protect public health and safety. An important aspct of this objective is to ensure that at the time of termination of facility operations (including premature closure) that adequate funds are available to decommission the facility resulting in its release for unrestricted use. Assurance of this availability of funds ensures that decommissioning can be accomplished in a safe and timely manner and that lack of funds does not result in delays in decommissioning that may cause potential health and safety problems for the public.

To satisfy this NRC decommissioning objective, the licensee must provide a high degree of assurance that adequate funds provided by the licensee will be available at the time of cessation of facility operations. This financial assurance must contain a mechanism enabling funds for the full cost of decommissioning to be made available at any time during facility operation.

In providing the high degree of assurance that funds are available for decommissioning, there are several possible funding mechanisms available to applicants and licensees. The wide diversity in types and complexity of nuclear facilities necessitates that NRC allow a wide latitude in the implementation of these funding mechanisms. Guidance as to what funding mechanisms provide adequate assurance has led to the following major classification of funding alternatives (used singly or in combination):

(1) Prepayment into an account segregated from other company funds prior to facility startup.

(2) Decommissioning insurance, surety bonds, letters of credit, and lines of credit that guarantee that decommissioning costs will be paid.

(3) Sinking funds - annual deposit of a prescribed amount of funds into an account segregated from other company funds. Decommissioning insurance, or other mechanisms of item (2), would also be required because premature closure would result in an insufficient collection of funds.

Another potential funding mechanism is referred to as internal reserve. While it is generally considered that this mechanism is less costly than the others, it has deficiencies because of the lack of assurance it, by itself, provides that funds will be available for decommissioning. Under NRC's responsibility to protect public health and safety, it would be considered an adequate funding mechanism only if were supplemented by substantial additional financing mechanisms that provided higher assurance.

The PNL decommissioning studies can be used, with suitable site-specific adjustments, for initial decommissioning cost estimates for the financial plan. Periodic updating of costs is required to reflect more current decommissioning information, as it evolves.

0.15.1.4 Residual Radioactivity Levels for Unrestricted Use of a Facility

The objective of selecting residual radioactivity levels is to provide a terminal level of radioactivity that will allow unrestricted access to a decommissioned facility and consequent NRC license termination. A selected residual radioactivity level must, of course, be safe and consistent with the ALARA (as low as is reasonably achievable) principle. In addition, selected levels for unrestricted facility access must be verifiable through actual detailed survey measurements of the facility and site, and be within reasonable bounds regarding state-of-the-art survey detection methodology and costs.

The EPA has the responsibility for setting decommissioning residual radioactivity levels which are considered safe for release of a facility for unrestricted access but have not yet done so. Discussions have been held with EPA relative to providing preliminary guidance for NRC in establishing these limits consistent with eventual EPA requirements.

Due to the variety of facility types and radionuclides involved it is not feasible to set a single dose limit that would be valid under all conditions for all facilities. It is necessary to assess the radiological impact in terms of the radionuclides and pathways involved and the costs and benefits which result. Based on these considerations and on consideration of the residual radioactivity limits discussed in this section, the following recommendations are made:

(1) A residual radioactivity level for permitting release of a nuclear facility for unrestricted use should be ALARA. Guidance in establishing such a limiting level is best expressed in terms of a value which bounds the dose for the majority of facilities discussed in this report. This value is determined to be 10 mrem/yr whole-body dose equivalent, but could be lower for specific facilities. The 10 mrem/yr limit in chosen recognizing that it may be impractical and unnecessary in some cases to meet the 5 mrem/yr limit mentioned in conclusion 2 of Section 2.5.2 because of cost-benefit considerations and problems in detectability, sampling, and/or exposure patterns. Discussions with EPA indicated that the 10 mrem/yr limiting value would not be considered unreasonable. In all cases, a dose limit above 1 mrem/yr would require justification. For a few situations, it is expected that residual limits will be outside the bounds of the 1 to 10 mrem/yr range. For these special situations, case-by-case analysis in terms of cost and benefit effectiveness will be required to establish appropriate limiting levels.

(2) Such dose rates and associated allowable contamination levels should be based on realistic dose assessment methodology. Realistic dose assessment recognizes, for example, that individuals do not spend all their time indoors, that building shielding should be accounted for, and that particulate resuspension diminishes due to weathering and decay.

A preliminary Oak Ridge National Laboratory study on residual radioactivity termination surveys has indicated that for a PWR, certification of a 5 mrem dose level is well within the technological capability and that certifying to this level can be done at reasonable cost.

There should be no significant additional decontamination effort required as a result of the termination survey, perhaps only cleanup of a few hot spots indicated by the survey. This is because the extensive efforts required to decontaminate the highly contaminated facility to low radioactivity levels will result in residual radioactivity levels well below the limits which permit unrestricted release of the facility. In addition, spot surveys will be carried out periodically during the decommissioning period so that at the time of the termination survey, the licensee is confident that decontamination efforts have achieved the acceptable residual radioactivity levels in most instances. Thus, because there should not be significant additional decontamination necessary after completion of the termination survey, the major cost and effort expected for verifying the required residual radioactivity levels will come from the certification survey. These costs of the survey are expected to be a small fraction of the total decommissioning cost.

In addition, cost-benefit considerations are involved in the evaluation of the extent of facility decontamination necessary to reduce radioactive contamination to levels considered acceptable for releasing the facility for unrestricted use. However, decontamination costs of a facility are essentially independent of the level to which it must be decontaminated as long as that level is in the range of 1 to 25 mrem/yr to an exposed individual.(1),(3) Therefore, cost-benefit considerations are not expected to have a major impact on the GEIS results concerning reactor and most nonreactor decommissionings. Cost-benefit may be a consideration in the removal of ore piles at non-fuel-cycle ore processing facilities where cost of disposal of the ore is very large.

0.15.2 REGULATIONS

Since, as indicated in Section 0.15.1, decommissioning requirements are an integral consideration in nuclear facility commissioning and operation, it is appropriate in terms of simplicity, efficiency, and reduction of regulatory burden, to amend the pertinent parts of the existing regulations to explicitly include appropriate decommissioning requirements, rather than develop a separate regulation.

To provide a clear presentation of the NRC overall decommissioning policy objectives and to establish the framework for rulemaking, it is recommended that an NRC decommissioning policy statement be issued prior to issuance of the proposed regulatory amendments.

Table 0.0-1

Summary of Estimated Radiation Doses from Decommissioning Nuclear Fuel Cycle Facilities (in man-rem)

	DECON	SAFSTOR			ENTOMB
		10 Years	30 Years	100 Years	
Occupational Exposure/Facility[a]					
Pressurized Water Reactor (PWR)	1,183[b]	652	329	304	920[c], 1,025[d]
Boiling Water Reactor	1,955	931	442	320	1,624[c], 1,753[d]
Fuel Reprocessing Plant	532	453	333	179	175
Small Mixed Oxide Plant	76	165	307	(e)	10
UF_6 Conversion Plant	1	1	1	1	(e)
Uranium Fuel Fabrication Plant	18.6	30	62	(e)	(e)
Independent Spent Fuel Storage Installation (ISFSI)	72	77	87	122	15
PWR at a Nuclear Energy Center	1,091	621	318	295	900[c], 1,000[d]
ISFSI at a Nuclear Energy Center	72	77	87	122	15
Public Exposure/Facility[a]					
Pressurized Water Reactor (PWR)	21[b]	7	3	2	3[c], 4[d]
Boiling Water Reactor	10	5	2	2	5[c], 7[d]
Fuel Reprocessing Plant	19	15	10	4	3
Small Mixed Oxide Plant	4	4	4	4	1
UF_6 Conversion Plant	0[f]	0	0	0	(e)
Uranium Fuel Fabrication Plant	1	1	1	(e)	(e)
Independent Spent Fuel Storage Installation (ISFSI)	0	0	0	0	
PWR at a Nuclear Energy Center	0	0	0	0	0[c], 0[d]
ISFSI at a Nuclear Energy Center	0	0	0	0	0

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[a] Data in this table calculated for the reference facilities as defined in the specific EIS section for that facility.

[b] Includes doses due to transportation of wastes.

[c] With reactor internals included.

[d] With reactor internals removed.

[e] Not calculated.

[f] 0 means negligible dose.

TABLE 0.0-2

Summary of Estimated Costs for Decommissioning Nuclear Fuel Cycle Facilities (in $Millions - based on 1978 dollars)(a)

	DECON	SAFSTOR			ENTOMB
Facility(b)		10 Years	30 Years	100 Years	
Pressurized Water Reactor (PWR)	33.3	41.2	42.8	41.8	21.0 + $40K/yr(c) 27.0 + $40K/yr(d)
Boiling Water Reactor (BWR)	43.6	57.4	58.9	55.0	35.0 + $40K/yr(c) 40.6 + $40K/yr(d)
Fuel Reprocessing Plant	76.0	88.0	105.0	167.0	37.0 + $40K/yr
Small Mixed Oxide Plant	7.8	16.3	28.3	(e)	2.8 + $10K/yr
UF_6 Conversion Plant	2.3	2.8	3.7	6.8	(e)
Uranium Fuel Fabrication Plant	3.5	8.9	17.5	(e)	(e)
Independent Spent Fuel Storage Installation (ISFSI)	4.6	6.4	7.3	10.5	3.3 + $46K/yr
PWR at a Nuclear Energy Center	29.2	36.6	37.4	35.5	18.9 + $20K/yr(c) 25.1 + $20K/yr(d)
ISFSI at a Nuclear Energy Center	4.3	6.1	7.0	10.2	3.0

(a) Costs for specific facilities are based on References 1 through 8. Table includes costs for equipment, supplies, power, materials, waste, labor and services plus a 25% contingency factor. Costs do not include cost for demolition of non-radioactive structures.

(b) Data in this table calculated for the reference facilities as defined in the specific EIS section for that facility.

(c) With reactor internals included.

(d) With reactor internals removed.

(e) Not calculated.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the National Technical Information Service.

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1.0 INTRODUCTION

Commercial nuclear facilities that come under the Nuclear Regulatory Commission's (NRC) regulatory authority include those dealing with fuel cycle and non-fuel-cycle operation. The generation of electric power from steam supplied by nuclear reactors requires a series of processes collectively known as the nuclear fuel cycle. This cycle begins with the mining and milling of uranium ore, includes the operation of power reactors, and ends with the disposition of radioactive wastes. Each step in the cycle requires the handling of radioactive materials, which are specifically designated as source materials, byproduct materials, or special nuclear materials. Non-fuel-cycle facilities can also use byproduct, source, and special nuclear materials. Non-fuel-cycle facilities include those involved in academic, pharmaceutical and industrial radioisotopic use and in rare metal ore processing. The handling of these materials and the processes involved have given rise to several issues of fundamental importance to the American public. These issues include the safe operation of all steps in the nuclear fuel cycle and of other nuclear facilities, especially the safe operation of power reactors; the safe disposition of radioactive wastes; and the safe decommissioning of all nuclear facilities. The first two issues have received much attention from Congress and from federal regulatory agencies, beginning in 1954 with the passage of the Atomic Energy Act. The third issue, decommissioning, is now receiving an increasing amount of attention because the nuclear field is reaching the degree of maturity that a number of facilities are nearing the end of their useful lives. It is this third issue which is the subject of this document.

1.1 PURPOSE OF EIS

The purpose of this environmental impact statement (EIS) is to assist the Nuclear Regulatory Commission (NRC) in developing new policies and in promulgating new regulations with respect to the planned decommissioning of commercial nuclear facilities (including decommissioning due to premature closure of facilities). It is prepared pursuant to the requirements of the National Environmental Policy Act (NEPA). Excluded from these considerations are decommissioning activities for uranium mill and mill tailings, and for shallow land low-level waste burial, which the NRC will consider separately in two additional environmental impact statements and separate rulemaking. In addition, also excluded are uranium mines which come under the jurisdiction of the states and other Federal agencies and deep geologic high-level waste burial which will be covered in separate rulemaking.

Decommissioning that occurs as a result of premature closure due to accidents may involve some technical and cost considerations not yet completely evaluated. A study to develop a data base on this subject for light-water-reactors will be initiated in fiscal year 1981, and a detailed report on decommissioning following a postulated accident, similar to those reports prepared for the facilities in this EIS, will be issued in fiscal year 1982. For other nuclear facilities the study will begin in fiscal year 1982. While the basic purpose and objectives for decommissioning facilities involved in accidents would be the same as for routine decommissioning, some of the specific aspects of the technology, safety, and costs of decommissioning may differ. Nevertheless, in many instances, these specific aspects would have similarities between accident and routine decommissionings. In particular, (1) decommissioning alternatives and timing may be similar for accident and routine situations; (2) planning and facilitation for accident decommissioning would consider essentially the same topics as routine decommissioning, although activities, methods, and procedures probably would be different; (3) financial considerations would be similar since the licensee would still have the responsibility of funding decommissioning and financing for premature closure decommissioning is addressed in the EIS, however, costs for accident decommissioning are not currently known and other means of assuring funding may be needed for accident decommissioning; and (4) the recommended residual radioactivity level limits would still be expected to apply, although the circumstances of the accident may require consideration of exceptions on an ALARA basis. It is not expected that major changes in the conclusions of this EIS will result from the technical studies on accident decommissioning, although there may be some differences in specific criteria. These items will be considered upon completion of the studies initiated in 1981 and 1982.

1.1.1 NEPA Requirements

Section 102(1) of the National Environmental Policy Act (42 U.S.C. 4321 et seq.) requires that "the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act." Section 102(2)(C) requires all agencies of the Federal Government to "include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on:

(i) the environmental impact of the proposed action,
(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
(iii) alternatives to the proposed action,
(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

1.2 ORGANIZATION OF THE EIS

The first three sections of this EIS contain material common to all of the facilities discussed in the statement. Regulatory matters are discussed in Section 1. Section 2 discusses in a generic manner the following: nuclear facilities; decommissioning alternatives; acceptable residual radioactivity levels for permitting release of the site for unrestricted access; financial assurance that sufficient funds are available for decommissioning; the management of radioactive wastes; and safeguards. Facility sites (i.e., the affected environment) are discussed generically in Section 3. Major facilities are discussed separately in Sections 4 through 12. A nuclear energy center is discussed in Section 13, and non-fuel-cycle nuclear facilities in Section 14. These sections include descriptions of each facility, discussions of decommissioning alternatives, and summaries of radiation exposures and decommissioning costs. Other environmental consequences are also discussed. Regulatory policy considerations are discussed in Section 15.

It is intended in this report to provide a document sufficient in detail to be useful to the NRC in establishing new policies and in promulgating new regulations, yet not so lengthy or detailed as to be overwhelming to the general public and to others who have a valid interest in the subject. Detailed reports have been, or are being, prepared which constitute information bases on the technology, safety and costs of decommissioning of the nuclear facilities discussed in this report.(1-8) These facilities are pressurized water reactors, boiling water reactors, fuel reprocessing plants, small mixed oxide fuel fabrication plants, uranium hexafluoride conversion plants, uranium fuel fabrication plants, multiple reactor power stations, and non-fuel-cycle materials facilities. Many of those reports have been available for critical comment for some time and have been found to be useful as a data base. These reports are currently being used by the nuclear industry in preparation of decommissioning studies. The decommissioning of uranium mills and tailings piles is discussed in a separate EIS.(10) The decommissioning of shallow-land low-level waste burial grounds is planned for discussion in a future EIS; however, a detailed technical report on this facility has recently been completed.(9)

This EIS represents a compendium of what would otherwise have been many separate EIS's on the nuclear facilities considered in this report. To make the report more useful to the user, the separate facility sections (section 4 through 14) were kept as self-contained as possible, so that a user interested in a particular facility type need primarily read only that section, as well as the introduction, the section on generic issues and the section on policy. Such an approach causes some unavoidable redundancy in presentation of information contained in the various facility sections. Also, in keeping with the objective of relatively self contained facility sections, this document contains a fairly detailed summary of the EIS which parallels, in format, the main body of the report. This is done so that the user can obtain a relatively complete picture of the report contents by reading the summary, and then go to the section of the main body of the report indicated by the summary for additional details. In addition, a brief overview of this report is presented to enable a user to gain a perspective of the objectives and conclusions reached in this report.

1.3 PURPOSE OF DECOMMISSIONING

The purpose of decommissioning nuclear facilities is to take the facility safely from service and to remove or to isolate the associated radioactivity effectively from the environment so that the facility can be released for unrestricted use. Alternative methods of accomplishing this purpose, and the environmental impacts of each alternative are discussed in this EIS.

1.4 RESPONSIBILITY FOR DECOMMISSIONING

The responsibility for decommissioning a commercial nuclear facility belongs to the licensee. Regulatory and policy guidance for decommissioning is the responsibility of the NRC and is implemented either by the NRC or Agreement State as applicable. Preparation for and implementation of decommissioning, including cost, is a requirement of the licensee.

1.4.1 Existing Criteria and Regulations for Decommissioning

Statutory authority for the regulation of activities related to the commercial nuclear fuel cycle is contained in the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) and the Energy Reorganization Act of 1974 (42 U.S.C. 5841 et seq.) and in subsequent amendments. Pursuant to these acts, the NRC has promulgated regulations which appear in Title 10 of the Code of Federal Regulations. The NRC has also published Regulatory Guides for the purpose of assisting applicants and licensees in carrying out their regulatory obligations.

Present decommissioning regulations are contained in 10 CFR Part 40 and in Section 50.33(f), Section 50.82, Appendix C and Appendix F of 10 CFR Part 50. General guidance is contained in NRC Regulatory Guides 1.86 and 3.5 (Rev. 1) and in NRC staff guidelines.

Section 50.33(f) and Appendix C to 10 CFR Part 50 require the applicant for a power reactor operating license to demonstrate financial capability both to operate the facility and to shut it down and maintain it safely. Should the licensee desire to terminate his license, section 50.82 requires the licensee to provide procedures for disposal of radioactive material, for decontamination of the site, and for assurance of public safety. Detailed decommissioning procedures need not be developed until the licensee desires to cease operating the facility. Paragraphs 4 and 5 of Appendix F of 10 CFR Part 50 require the applicant for a fuel reprocessing plant operating license to develop criteria "for the extent of decontamination to be required upon decommissioning and license termination," and to demonstrate financial capability to decommission the facility. In addition, a design objective shall be to facilitate decommissioning.

A recent amendment to the Atomic Energy Act of 1954 is the Uranium Mill Tailings Radiation Control Act of 1978. This act expands the authority of the NRC and agreement states under the Atomic Energy Act to control uranium mill tailings. Among other things the act discusses the decommissioning of uranium mill tailings piles. A final EIS on uranium milling has been prepared.(10) Based on the Act and conclusions in the EIS, regulations have been promulgated by the NRC in 10 CFR Part 40 and Appendix A of Part 40.

10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage Installation," requires an applicant for a license to present a decommissioning plan which includes procedures and financial arrangements for decommissioning. The regulation also requires that the facility be designed to facilitate decontamination and decommissioning. The regulation was published in the Federal Register on November 12, 1980 (45 FR 74693).

Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors," describes four acceptable alternatives which can be undertaken at the end of reactor life: mothballing or protective storage, in-place entombment, removal of radioactive components and dismantling, and conversion to a new nuclear or fossil fuel system. Regulatory Guide 1.86 also states the requirements for a possession-only license and the criteria by which a decontaminated reactor is judged to be suitable for release for unrestricted access or use.

An NRC staff guideline issued in November 1976,(11) "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," states the criteria by which a nonreactor decontaminated nuclear facility may be judged to be acceptable for release to unrestricted use.

Regulatory Guide 3.5 (Rev. 1), "Standard Format and Content of License Applications for Uranium Mills," describes information needed in the application and sets interim criteria for tailings pile stabilization.

A more detailed review of existing statutes, regulations, and guidelines appears in Reference 12.

1.4.2 Proposed Rulemaking

The NRC is currently considering developing a more explicit overall policy for decommissioning commercial nuclear facilities and amending its regulations in 10 CFR Chapter I to include more specific decommissioning guidance for production and utilization facility licensees and byproduct, source, and special nuclear material licensees.(11) Specific licensing requirements are being considered that include the development of decommissioning plans and financial arrangements for decommissioning nuclear facilities. Preliminary staff views on such requirements have recently been presented.(13,14)

Critical issues requiring resolution in developing or reevaluating decommissioning policy and in promulgating new regulations are 1) acceptable residual radioactivity levels for permitting release of the site for unrestricted access, 2) financial assurance that funds are available for decommissioning, and 3) the applicability of generic analyses to the decommissioning of specific facilities. Guidance on Item 3 is being developed through inclusion in the information base studies of sensitivity analyses of such parameters as the size of the facility, contamination level, waste disposal costs, labor costs, etc.

1.5 HISTORY, BACKGROUND, AND EXPERIENCE WITH DECOMMISSIONING

The three types of facilities identified with the portion of the nuclear fuel cycle between mining and reactor operation call for relatively routine decommissioning procedures: uranium mills, uranium hexafluoride conversion plants, and uranium fuel fabrication plants. (Uranium enrichment plants are a part of this portion of the fuel cycle. However, none of these facilities are licensed by NRC. Decommissioning impacts from such facilities are expected to be similar to the above listed facilities). These facilities usually contain low-level radioactivity which is well confined to the facility. Uranium mill tailings piles also contain low levels of radioactivity, but they can be extensive in size, are usually on the ground open to air and water pathways, and emit ^{222}Rn. Mixed oxide fuel fabrication plants involve plutonium and thus call for special procedures. Pressurized water reactors, boiling water reactors, fuel reprocessing plants, and spent fuel storage facilities contain high levels of radioactivity that require very special precautions and procedures. Shallow-land low-level burial grounds generally contain low levels of radioactivity; but they may also contain highly activated reactor parts. Because they are usually accessible to air and water, shallow-land low-level burial grounds also call for special decommissioning procedures. The complexity of decommissioning non-fuel-cycle facilities that handle byproduct, source, or special nuclear materials depends on the materials handled; the magnitude of decommissioning difficulties lies rather more in the great number and variety of licensed facilities than in any technical difficulties.

Since 1960, five licensed power reactors, four demonstration reactors, six licensed test reactors, one licensed ship reactor, and 52 licensed research reactors and critical facilities have been or are being decommissioned by the methods discussed in this EIS. Forty-two research reactors and critical facilities have been dismantled. Only one power reactor, the Elk River demonstration reactor, has been completely dismantled. Three other demonstration power reactors of small size have been entombed. The decommissioning status of the more important reactors is listed in Table 1.5-1. Some military reactors are included, while licensed research reactors and critical facilities have been omitted.

Decommissioning experience with some of the specific types of facilities is limited, but a broad base of experience with various facilities exists which is generally relevant to the decommissioning of any type of nuclear facility. A sampling of non-reactor facilities which have been decommissioned is presented in Table 1.5-2.

Increased interest has recently been shown in decommissioning by the public, Congress, the NRC, electric utilities, and federal and state regulatory agencies. For example, the General Accounting Office reported to Congress on "Cleaning Up the Remains of Nuclear Facilities--A Multibillion Dollar Problem," EMD-77-46, June 16, 1977. Also, at least six state regulatory commissions are considering the problem of financing decommissioning(13) (Florida, Pennsylvania, California, Illinois, Wisconsin, and New York). The Wisconsin Public Service Commission is considering a moratorium on construction of nuclear power plants in Wisconsin beyond the two now under consideration by the PSC until uncertainties in waste disposal and decommissioning are resolved.(14) In addition, the state legislatures of seven states have passed bills requiring that funding be established to ensure decommissioning of uranium mills and mill tailings.

TABLE 1.5-1. Summary of Nuclear Reactor Decommissionings

Facility Name and Location	Reactor Type	Power Rating[a]	Type of Decommissioning	License Status	Monitoring System	Safe Storage Measures	Year Decommissioned	Other Information
HRE-1 (Homogeneous Reactor Experiment), Oak Ridge, TN	Fluid-fuel	1 MWt	Dismantled	-[b]	-	-	1954	-
HRE-2 (Homogeneous Reactor Experiment), Oak Ridge, TN	Fluid-fuel	<1 MWt	Dismantled	-	-	-	1954	-
ARE (Aircraft Reactor Experiment), Oak Ridge, TN	Fluid-fuel	3 MWt	Dismantled	-	-	-	1955	-
PM-2A (Portable Medium Power Plant), Greenland	PWR	10 MWt	Dismantled	-	-	-	1964	-
Hanford Production Reactors, Richland, WA	Graphite moderated, water cooled	-	Custodial Safe Storage (Lay-away), 4-Stand-by, 4-Retired	-	Continuous surveillance by DOE	Continuous maintenance by DOE	1965-1971	One planned for dismantling
CVTR (Carolina Virginia Tube Reactor), Parr, SC	Pressure tube, heavy water cooled and moderated	65 MWt	Passive Safe Storage (mothballed)	Byproduct State[c]	Periodic surveillance	Welded closure, locked doors, security fence	1968[d]	-
Hallam Nuclear Power Facility, Hallam NB	Graphite moderated, sodium cooled	256 MWt	Entombed	Operating authorization terminated	Periodic surveillance by DOE	Welded closure, concrete cover, weatherproofed	1969	Decommissioning took 3 years
Piqua Nuclear Power Facility, Piqua, OH	Organic cooled and moderated	45 MWt	Entombed	Operating authorization terminated	Periodic surveillance by DOE	Welded closure, concrete cover, waterproofed	1969	Decommissioning took 3 Years
BONUS (Boiling Nuclear Superheater Power Station, Ricon, PR	BWR with nuclear superheating	50 MWt	Entombed	Operating authorization terminated	Periodic surveillance by DOE	Welded closure, concrete cover, security fence	1970	-
Walter Reed Research Reactor, Washington, DC	AI Model L-54, homogeneous fuel	50 kWt	Dismantled	-	-	-	1971	-
Pathfinder, Sioux Falls, SD	BWR with nuclear superheating	190 MWt	Passive Safe Storage (mothballed) with steam plant conversion	Byproduct NRC[c]	Continuous security force[e]	Welded closure, security fence	1972	Decommissioning cost $3.7M
B&W, Lynchburg, VA	Pool	6 MWt	Partially Dismantled	Byproduct NRC	Continuous security force	Locked doors, security fence	1972	-
EBR-I (Experimental Fast Breeder Reactor), Scottsville, ID	Liquid metal cooled	-	Deactivated, decontaminated, converted for public access	-	-	-	19[illegible]	Dedicated a National Monument in 1966
Saxton Nuclear Experimental Facility, Saxton, PA	PWR	23 MWt	Passive Safe Storage (mothballed)	Possession only[f]	Intrusion alarms	Welded closure, locked doors, security fence	1973	Decommissioning cost $2.5M
SEFOR (Southwest Experimental Fast Oxide Reactor), Strickler, AR	Sodium cooled, fast	20 MWt	Passive Safe Storage (mothballed)	Byproduct State	Intrusion alarms	Welded closure, locked doors, security fence	1973	-
Elk River Reactor, Elk River, MN	BWR with fossil superheating	58 MWt	Dismantled with steam plant conversion	Terminated[g]	Not required	Not required	1974	Decommissioning cost $6.15M; took 3 years
ASTR (Aerospace Test Reactor), U.S. Air Force, NARF, Ft. Worth, TX	-	10 MWt	Dismantled	-	-	-	1974	-
GTR (Ground Test Reactor), U.S. Air Force, NARF, Ft. Worth, TX	-	10 MWt	Dismantled	-	-	-	1974	-
RTA (Reactivity Test Assembly), U.S. Air Force, NARF, Ft. Worth, TX	-	1 MWt	Dismantled	-	-	-	1974	-
FERMI 1, Monroe Co. MI	Sodium cooled, fast	200 MWt	Passive Safe Storage (mothballed) with steam plant conversion	Possession only	Continuous security force	Locked doors, security fence	1975	Decommissioning cost $6.95M
PM-3A (Portable Medium Power Plant), Antarctica	PWR	9 MWt	Dismantled	-	-	-	1977	-
HTR (Hanford Test Reactor), Richland, WA	Graphite moderated	Zero Power	Dismantled	-	-	-	1977	Decommissioning cost $0.18M
IRL (Industrial Reactor Laboratories Inc. Research Reactor), Plainsboro, NJ	Pool	5 MWt	Partially dismantled	-	-	Unrestricted use	1977	Decommissioning cost $1M; took 2 years
GE EVESR, Alameda Co., CA	BWR with nuclear superheating	[illegible] MWt	Passive Safe Storage (mothballed)	Possession only	Continuous security force	Locked doors, security fence	-	-
NASA Plumbrook, Sandusky, OH	Light water	100 KWt	Passive Safe Storage (mothballed)	Possession only	Continuous security force	Locked doors, security fence	-	-
Peach Bottom 1, York Co., PA	Gas cooled, graphite moderated	115 MWt	Passive Safe Storage (mothballed)	Possession only	Continuous security force	Not yet established	-	-
VBWR (Vallecitos Boiling Water Reactor), Alameda Co., CA	BWR	50 MWt	Passive Safe Storage (mothballed) with steam plant conversion	Possession only	Continuous security force	Locked doors, security fence	-	-
Westinghouse Test Reactor, Waltz Mills, PA	Tank	60 MWt	Passive Safe Storage (mothballed)	Possession only	Continuous security force	Locked doors, security fence	-	-
SRE (Sodium Reactor Experiment), Santa Susana, CA	Graphite moderated, sodium	30 MWt	Passive Safe Storage (mothballed - 1967) dismantling started 1976	-	-	-	Dismantling in progress	Decommissioning costs expected to be ~$10M

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[a] Power ratings are given in thermal megawatts (MWt) or kilowatts(kWt).
[b] Dash indicates information is unavailable from the literature studies or is not applicable.
[c] Byproduct licenses may be either "Byproduct NRC" issued in accordance with 10 CFR Part 30 or "Byproduct State" issued by an agreement state in accordance with authority granted by 10 CFR Part 150.
[d] First to be placed in passive safe storage (mothballed); provided significant experience in developing criteria and methods.
[e] Implies the availability of other onsite security forces not specifically associated with the decommissioned facility. Had such not been available, NRC may have required other control measures.
[f] Title 10 CFR Part 50 §50.82 provides the rule by which a licensee may amend his operating license to a possession-only license. Once this possession-only license is issued, reactor operation is not permitted.
[g] The site is the first decommissioned commercial reactor to be approved by the government for unrestricted use.

TABLE 1.5-2. Nonreactor Nuclear Facility Decommissioning Information

Facility	Location	Year Decommissioned	Type of Decommissioning
Polonium-210 Facilities (Units III & IV)	Miamisburg, Ohio	1950	Partial dismantlement; decontaminated to unrestricted release levels
Cave Facility (Radium-226 and (Actinium-227 Processing Facility)	Miamisburg, Ohio	1967	Partial entombment, remainder decontaminated to unrestricted release levels
SM Facility (Space Programs Plutonium-238 Facility)	Miamisburg, Ohio	1972	Decontaminated and placed in passive safe storage (mothballed) awaiting final disposition by DOE
Plutonium Filter Facility (Building 12)	Los Alamos, NM	1973	Dismantled
Laboratory for Plutonium Criticality Studies (P-11)	Richland, WA	1974	Dismantled
Plutonium Physics Study Building No. 21	Los Alamos, NM	1975	Dismantled

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the National Technical Information Service.

***Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

2.0 GENERIC NUCLEAR FACILITY DECOMMISSIONING CONSIDERATIONS

In this section consideration is given to generic items required for implementing a decommissioning program for the facilities considered in this EIS. First, for an overview, a brief discussion is presented of the nuclear fuel cycle for light-water-reactors. Non-fuel-cycle nuclear facilities are also briefly discussed. Consideration is then given to:

(1) Decommissioning alternatives and their advantages and disadvantages,

(2) Acceptable residual radioactivity levels for permitting release of a decommissioned nuclear facility for unrestricted access,

(3) Assurance that funds to pay for decommissioning will be available,

(4) Waste management for disposing of radioactive waste associated with nuclear facility decommissioning, and

(5) Safeguard requirements during decommissioning.

2.1 NUCLEAR FACILITIES OPERATIONAL DESCRIPTION

2.1.1 The Nuclear Fuel Cycle

A nuclear power plant is a facility designed to generate electricity by utilizing the heat produced by controlled nuclear fission of uranium and plutonium. This is the desired production step in the fuel cycle. It is preceded by several steps in the fuel cycle in which uranium ore is processed into fuel elements, and is followed by several steps in which fuel removed from the reactor is stored and then either reprocessed to recover usable fuel or disposed of in some manner. The basic steps in the nuclear fuel cycle are shown in Figure 2.1-1. Each box in the diagram represents a separate facility and each arrow represents the transportation of the product between facilities. The steps indicated by a dashed line are not now operating. Spent fuel is being stored at the reactor sites as a result of the indefinite deferral of reprocessing and mixed oxide fuel fabrication and the continued study of ultimate (geologic) disposal.

The steps in Figure 2.1-1 for the typical fuel cycle for power plants are described more fully below.

Milling

The uranium ores that are mined and milled in the United States are sedimentary deposits in which the uranium occurs as a coating on sand grains. Small quantities of radium and thorium are also found in the ore. The uranium content is only about 1 to 3 kg per tonne (2 to 6 lb per ton) of ore. The milling process dissolves the uranium and separates it from the sand. This involves crushing and grinding the ore, dissolving the uranium by acid or alkaline leach, and precipitating a semi-refined product, called yellowcake. The tailings from this process are

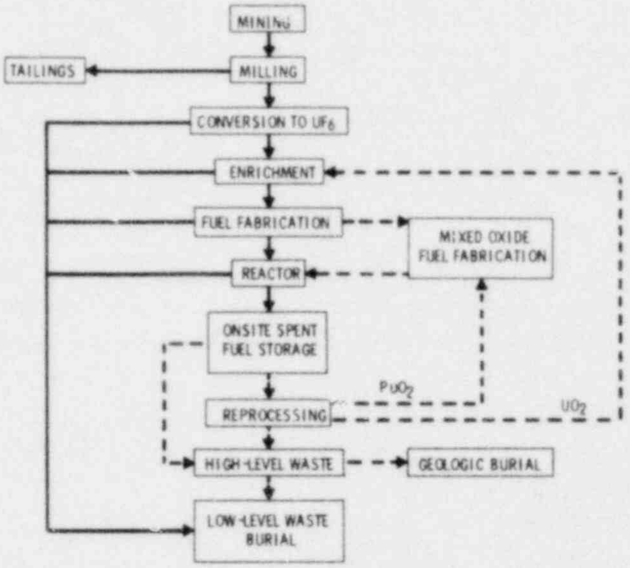

FIGURE 2.1-1. Diagram of the Steps in the Nuclear Fuel Cycle

mostly sand, but they also include the original quantities of radium, thorium, and other decay products that do not extract with the uranium. The tailings are carried as a slurry to impoundment areas where the water is allowed to evaporate. The tailings are then stabilized to reduce future potential contamination problems.

Conversion

The yellowcake is shipped to a conversion plant where it is converted to UF_6 by one of two processes. One is the "dry" or hydrofluor process in which the yellowcake goes through a series of reduction, hydrofluorination, and fluorination steps in fluidized bed reactors. The other is a "wet" process in which the yellowcake is first processed to produce a high-purity uranium dioxide feed that undergoes reduction, hydrofluorination, and fluorination.

Enrichment

The UF_6 produced by the conversion process contains about 0.7 % ^{235}U, which must be increased to 2 to 4% prior to fabrication into LWR fuel assemblies. Enrichment is accomplished by a gaseous diffusion process in which $^{235}UF_6$ molecules pass more readily through a porous membrane than do $^{238}UF_6$ molecules, thus producing a product stream that is enriched in $^{235}UF_6$. This process is repeated through many such stages until the desired degree of enrichment is attained. The enriched UF_6 is then shipped to a fuel fabrication plant.

Fuel Fabrication

In the preparation of LWR fuel, the enriched UF_6 first undergoes chemical treatment to convert it to UO_2. The UO_2 is mechanically and thermally treated to produce high-density ceramic fuel pellets that are placed in metal fuel tubes. These tubes or rods are then clustered into fuel assemblies for reactor cores.

Reactors

A light water reactor (LWR) as used in a power plant utilizes the heat produced by controlled nuclear fission within the fuel assemblies in the reactor core to heat water and generate steam which drives a turbine-generator.

There are two basic LWR types: the pressurized water reactor (PWR) and the boiling water reactor (BWR). In a PWR the water in the reactor core is kept under pressure to allow heat build-up without boiling. This heated water is circulated through a heat exchanger where water in a second circulating system is converted to steam to drive the turbines. In a BWR the water in the reactor core is allowed to boil, directly producing the steam to drive the turbines.

Spent Fuel Storage Facilities

The partially depleted or LWR spent fuel assemblies are removed from the reactor and stored in spent fuel pools at the reactor for a minimum of 90 days. This cooling period allows the short-lived radionuclides to decay and reduce the radioactivity and thermal heat emission of the fuel assemblies.

As indicated in Section 2.1.1 spent fuel is currently being stored at reactor spent fuel pools for extended time periods because plans for further disposition of the spent fuel are still under study. Since the number of spent fuel assemblies that can be stored at reactor spent fuel pools is limited, storage of spent fuel at away-from-reactor independent spent fuel storage installations (ISFSI) is being considered as an interim measure. The design of the ISFSI is similar to that of the reactor storage pools except that the storage capacity is significantly greater. An alternative ISFSI design is to store the spent fuel in a dry storage environment such as an air-cooled vault.

Fuel Reprocessing

LWR spent fuel assemblies can be chemically reprocessed to separate the remaining uranium and the generated plutonium from the radioactive wastes produced during reactor operation. The chemical separation is accomplished by chopping the fuel rods into short sections, dissolving the pellets with nitric acid, extracting uranium and plutonium nitrates from the fission products, and then separating the uranium from the plutonium. The urany. nitrate is converted to UF_6 and the plutonium nitrate is oxidized to plutonium dioxide. Both can then be inserted into the fuel cycle for reuse.

At the present time no commercial spent fuel is being reprocessed. Thus, spent fuel is accumulating in onsite reactor storage pools. Offsite spent fuel storage facilities offer an interim alternative to onsite storage.

Mixed Oxide Fuel Fabrication

A mixed oxide fuel fabrication plant produces fuel elements that contain a mixture of UO_2 and PuO_2. In this process, UO_2 and PuO_2 powders are mixed and the mixture is formed into pellets by mechanical and thermal treatment. These pellets are sealed in metal cladding to form fuel elements. Only small mixed oxide plants are currently in use commercally and are used to fabricate experimental fuel elements.

Low-Level Waste Burial Grounds

Low-level radioactive wastes which do not contain transuranic elements above certain concentrations are disposed of in shallow-land burial sites. These kinds of materials may be generated at reactors or at any of the facilities where fuel is processed, and consist of contaminated trash, filters, and equipment. These wastes are placed in boxes or drums to facilitate handling and are buried in shallow trenches at sites that are monitored and do not have public access.

High-Level Waste Burial Grounds

High-level wastes are either intact fuel assemblies that are being discarded after serving their useful life in a reactor core (spent fuel) or certain fission product and actinide wastes generated during fuel reprocessing. Studies are presently being made of high-level waste burial at deep geologic repositories. There are currently no facilities of this type.

2.1.2 Non-Fuel-Cycle Nuclear Facilities

Non-fuel-cycle facilities are those facilities which handle by-product, source and/or special nuclear materials, but which are not involved in the production of power as outlined in Figure 2.1.-1. Non-fuel-cycle facilities must be licensed by the NRC. Precise definitions and licensing requirements for the materials listed above are published in 10 CFR Parts 30, 40, and 70, respectively. Broadly speaking, source materials consist of uranium and thorium, special nuclear materials consist of plutonium or enriched uranium, and byproduct materials consist of materials made radioactive by special nuclear material. These facilities include a wide range of applications in industry, medicine and research such as manufacture of packaged products containing small sealed sources and of radiochemicals, research and development institutions, and processors of ores in which the tailings contain licensable quantities of radionuclides.

2.2 FACILITIES CONSIDERED IN EIS

The facilities considered in this EIS are: 1) pressurized water reactors, 2) boiling water reactors, 3) fuel reprocessing plants, 4) small mixed oxide fuel fabrication plants, 5) uranium hexafluoride conversion plants, 6) uranium fuel fabrication plants, 7) independent spent fuel storage installations, 8) nuclear energy centers, and 9) non-fuel-cycle nuclear facilities. The facilities not considered include uranium mills and mill tailings, and low-level waste and high-level waste burial grounds because they are covered by separate rulemaking; and uranium mines and the existing government owned uranium enrichment plants because they are not under NRC jurisdiction.

2.3 DEFINITION OF DECOMMISSIONING

Decommissioning means to safely remove the property from radioactive service and to dispose of radioactive materials. The level of any residual radioactivity remaining on the property after decommissioning must be low enough to allow unrestricted use of the property.

2.4 DECOMMISSIONING ALTERNATIVES

Once a nuclear facility has reached the end of its useful life, it must be decommissioned (i.e., placed in a condition such that there is no unreasonable risk from the decommissioned facility to public health and safety). Several alternatives are possible, although not all may be satisfactory for all nuclear facilities. These alternatives are: no action, DECON, SAFSTOR, and ENTOMB. The terms DECON, SAFSTOR, and ENTOMB are relatively new in use. In the past, the nomenclature for describing these alternatives has not been consistent. Different documents have often used different terminology when referring to the same decommissioning alternative, thus causing some confusion. In the interest of ending the confusion, this section lists the following definitions of the major decommissioning alternatives and the following pseudoacronyms to clearly delineate each alternative:

> DECON means to immediately remove all radioactive material down to residual levels which permit release of the property for unrestricted access.

SAFSTOR means to fix and maintain the property so that risk to safety is acceptable for a period of storage followed by decontamination and/or decay of radioactivity to levels which permit release of the facility for unrestricted access.

ENTOMB means to encase and maintain the property in a strong and structurally long-lived material (e.g., concrete) to assure retention until all radioactivity decays to levels which permit release of the property for unrestricted access.

To provide a transition from other terminology to that listed here, the following sections and Table 2.4.-1 include, in parentheses, nomenclature that has been used previously. Table 2.4-1 presents a summary of the various activities that will be in effect during DECON, SAFSTOR and ENTOMB.

Conversion to a new or modified use is also considered. Conversion, however, is not a true decommissioning alternative whether the new use involves radioactivity or not. If the intended new use involved radioactive material and, thus was under NRC licensing authority, an application for the new use would be reviewed as amendments to the existing license under appropriate existing regulations. If the intended new use does not involve radioactive materials, i.e., unrestricted public access, and does not come under NRC licensing authority, then such application for a new use would be reviewed as a request for decommissioning and termination of license. As such, it would have to use one of the decommissioning alternatives indicated above, namely DECON, SAFSTOR, or ENTOMB. In this case, the new use is not important except as it affects the decommissioning alternative chosen and the evaluation of residual radioactivity levels for unrestricted facility use. For these reasons, conversion to a new or modified facility is not considered further in this EIS.

2.4.1 No Action

The objective of decommissioning is to return a radioactive facility to the public domain in a condition such that there is no unreasonable risk from the decommissioned facility to public health and safety. In order to ensure that at the end of its life the risk from a facility is within acceptable bounds, some action is required, even if it is as minimal as making a terminal radiation survey to verify the radioactivity levels and notifying the NRC of the results of the survey. Thus, independent of the type of facility and its level of contamination, No Action, implying that a licensee would simply abandon or leave a facility after ceasing operations, is not a viable decommissioning alternative. Therefore, since no action is not considered viable for any facility discussed in this EIS, this alternative is not considered further in this report.

2.4.2 DECON

DECON means to immediately remove all radioactive materials down to levels which are considered acceptable to permit the property to be released for unrestricted use. DECON is the only one of the decommissioning alternatives presented here which leads to termination of the facility license and release of the facility and site for unrestricted use shortly after cessation of facility operations. DECON is estimated to last from fairly short time periods for small facilities to up to approximately 4 years for a large PWR.

Since all of the DECON work is completed within a few months or years following facility shutdown, personnel radiation exposures are generally higher than for other decommissioning alternatives which spread the decommissioning work over longer time periods thus allowing for radioactive decay. Similarly, larger commitments of money and waste disposal site space are also required for DECON in a relatively short time frame compared to the other alternatives.

TABLE 2.4-1 Summary of the Elements of the Decommissioning Alternatives

Elements[a]	Facility Status	Comments, Facility/Site Use
Decontamination [to levels permitting unrestricted use of the facility] (Dismantlement)[b]	Equipment - removed if radioactive Continuing Care Staff - none Security - none Environmental Monitoring - none Radioactivity - removed Surveillance - none Structures - removal optional	Facility - Unrestricted use after reaching permissable levels Site - Unrestricted use after reaching permissable levels
Safe Storage		
Custodial (Layaway)[b]	Equipment - some operating Continuing Care Staff - some required Security - continuous Environmental Monitoring - continuous Radioactivity - confined Surveillance - continuous Structures - intact	Safe storage alone is not an acceptable decommissioning mode; it must be followed by decontamination to unrestricted use. Facility - Nuclear Only Site - Nuclear Only
Passive (Mothball, Protective Storage)[b]	Equipment - none operating Continuing Care Staff - optional (onsite) - routine inspections Security - remote alarms Environmental Monitoring - routine periodic Radioactivity - immobilized/sometimes sealed Surveillance - periodic Structures - intact	Facility - Nuclear Only Site - Conditional Non-nuclear
Hardened (Temporary Entombment)[b]	Equipment - none operating Continuing Care Staff - none on site Security - hardened barriers, fencing and posting Environmental Monitoring - infrequent Radioactivity - hardened sealing Surveillance - infrequent Structures - partial removal optional	Facility - Conditional Non-nuclear Site - Conditional Non-nuclear
Entombment	Equipment - some removed, the rest encased in concrete Site - Unrestricted Continuing Care Staff - none Security - hardened barriers Environmental Monitoring - infrequent Radioactivity - encased in concrete Surveillance - infrequent Structures - intact	Facility - Unusable for an Extended time period Site - Unrestricted use

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[a] Elements are the specific activicies involved in each of the decommissioning alternatives, e.g., SAFSTOR is is made up of the following elements: preparation for safe storage, safe storage and decontamination.

[b] This nomenclature is that used in previous decommissioning reports and is included here for information.

Thus, the primary advantage of DECON, which is terminating the facility license and making the facility and site available for some other beneficial use, is accomplished at the expense of larger initial commitments of money, personnel radiation exposure, and waste disposal site space than for the other alternatives. However, for some facilities, DECON results in less overall dose and cost. Other advantages of DECON include the availability of a work force highly knowledgeable about the facility and the elimination of the need for long-term security, maintenance and surveillance of the facility which would be required for the other decommissioning alternatives.

In DECON, nonradioactive equipment and structures need not be torn down or removed as part of a decontamination procedure. In addition, once the radioactive facility structures are decontaminated to radioactivity levels permitting unrestricted use of the facility, they may either be put to some other use or demolished at the owner's option.

2.4.3 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a radioactive facility in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination). SAFSTOR consists of a short period of preparation for safe storage (up to 2 years), a variable safe storage period of continuing care consisting of security, surveillance, and maintenance (up to 100 years depending on the type of facility; 100 years is consistent with recommended EPA policy on institutional control reliance for radioactivity containment), and a short period of deferred decontamination. Several subcategories of SAFSTOR are possible:

1. Custodial SAFSTOR [layaway(a)] requires a minimum cleanup and decontamination effort initially, followed by a period of continuing care with the active protection systems (principally the ventilation system) kept in service throughout the storage period. Full-time onsite surveillance by operating and security forces is required to carry out radiation monitoring, to maintain the equipment, and to prevent accidental or deliberate intrusion into the facility and the subsequent exposure to radiation or the dispersal of radioactivity beyond the confines of the facility.

2. Passive SAFSTOR [protective storage,(a) mothballing(b)] requires a more comprehensive cleanup and decontamination effort initially, sufficient to permit deactivation of the active protective (ventilation) system during the continuing care period. The structures are strongly secured and electronic surveillance is provided to detect accidental or deliberate intrusion. Periodic monitoring and maintenance of the integrity of the structures is required.

3. Hardened SAFSTOR [temporary entombment(c)] requires comprehensive cleanup and decontamination and the construction of barriers around areas containing significant quantities of radioactivity. These barriers are of sufficient strength to make accidental intrusion impossible and deliberate intrusion extremely difficult. Surveillance requirements are limited to detection of attack upon the barriers, to maintenance of the integrity of the structures, and to infrequent monitoring.

(a) This nomenclature is used in NUREG-0278 (Reference 1).

(b) This nomenclature is used in Regulatory Guide 1.86 (Reference 2).

(c) This nomenclature is used in AIF/NESP-009 (Reference 3).

All categories of safe storage require some positive action at the conclusion of the period of continuing care to release the property for unrestricted use and terminate the license for radioactive materials. Depending on the nature of the nuclear facility and its operating history, the necessary action can range from a radiation survey that shows that the radioactivity has decayed and the property is releasable, to dismantlement and removal of residual radioactive materials. These latter actions, whatever their scale, are generically identified as deferred decontamination.

SAFSTOR is used as a means to satisfy the requirements for protection of the public while minimizing the initial commitments of time, money, occupational radiation exposure, and waste disposal space. Modifications to the facilities are limited to those which ensure the security of the buildings against intruders, and to those required to ensure containment of radioactive or toxic material. It is not intended that the facilities will ever be reactivated. In highly contaminated facilities and/or facilities with large amounts of activation products, there is the potential for incurring larger occupational radiation exposures if complete decontamination is performed immediately after shutdown (DECON). However, as a result of radioactive decay of this contamination, reductions in personnel exposure and simplifications in the complexity of operations can be achieved by deferring major decontamination efforts for a number of years (up to 100 years depending on the type of facility). Also, because many of the contamination and activation products present in the facility will have decayed to background levels after a lengthy storage period, the volume of material that must be packaged for disposal will be reduced.

The reduced initial effort (and cost) of the preparation for safe storage is tempered somewhat by the need for continuing surveillance and physical security to ensure the protection of the public. Electronic surveillance devices, which are presently available, could be in service fulltime, with offshift readouts in a local law enforcement office or private security agency. These devices which monitor for intruders, increases in radiation levels, and detection of fires will require periodic checks and maintenance.

Maintenance of the facility's structures and an ongoing program of environmental surveillance are also necessary. The duration of the storage and surveillance period can vary from a few years to approximately 100 years depending on the type of facility. (100 years is consistent with recommended EPA policy on institutional control reliance for radioactivity containment.) If SAFSTOR is used, the decision on the length of the safe storage period will be made by the facility owner, with the approval of the NRC, based on consideration of such factors as desirability of terminating the license, radiation dose reductions, and cost. For example, if the value of the property for unrestricted use is large and the cost of continuing care is also large, there is an incentive to decontaminate the facility earlier than would otherwise be dictated by the decay of radioactivity within the facility, even though the occupational exposure would be higher. Similarly, the decision on the extent of decontamination during the period of preparation for safe storage, and the resultant subcategory of SAFSTOR to be used, depends upon safety considerations, the cost of continuing care and the planned length of the storage and surveillance period. If for example, ^{60}Co is the controlling source of occupational exposure, a chemical decontamination campaign achieving a decontamination factor (DF) of 10 (i.e., radioactivity levels reduced to 1/10 of original) will result in approximately the same dose reduction as a decay period of 17 years.

At the end of the period of safe storage, several things will remain to be done before the facility can be released for unrestricted use. In most cases, radioactivity in some areas within the facility will be significantly above levels acceptable for unrestricted release of the facility, necessitating the removal, packaging and disposal of selected materials at a regulated disposal site. If the safe storage period is sufficiently long, radioactive materials in the facility may have decayed to levels low enough to permit the facility to be released for unrestricted use without additional decontamination. This would not apply in the case of a reactor, if the reactor had been operated long enough to produce significant amounts of the long-lived isotopes ^{59}Ni and ^{94}Nb.

Deferred decontamination, even for a major facility such as a PWR, is a relatively straight-forward disassembly job complicated by whatever radioactivity remains. Removal and transport of the materials containing the radioactivity to a disposal site are the principal tasks that must be completed. Further action, such as disassembly of the various non-radioactive systems and use or demolition of the buildings, would be at the owner's discretion.

A disadvantage of SAFSTOR is the potential lack of personnel familiar with the facility at the time of deferred decontamination. More time for training and orientation would be needed if the procedures required are extensive. One potential solution to this problem would be the establishment of companies specializing in the decommissioning of nuclear reactor power stations and other nuclear facilities. Other disadvantages include the fact that the site is tied up in a non-useful purpose for extended time period, regulatory uncertainties in the future, possible regulatory problems with agreement states, state public utility commissions, or state legislatures, and the continuing need for maintenance, security and surveillance.

2.4.4 ENTOMB

ENTOMB means to encase and maintain property in a strong and structurally long-lived material (e.g., concrete) to assure retention until radioactivity decays to a level acceptable for releasing the facility for unrestricted use. ENTOMB is intended for use where the residual radioactivity will decay to levels permitting unrestricted release of the facility within reasonable time periods (i.e., within the time period of continued structural integrity of the entombing structure; approximately 100 years is considered to be consistent with recommended EPA policy on institutional control reliance for radioactivity containment). However, a few radioactive isotopes found in fuel reprocessing plants, nuclear reactors, fuel storage facilities, or MOX facilities have half-lives in excess of 100 years and the radioactivity will not decay to levels permitting release of the facilities for unrestricted use within the foreseeable lifetime of any man-made structure. Thus, the basic requirement of continued structural integrity of the entombment cannot be ensured for these facilities, and ENTOMB is not a viable alternative. On the other hand, if the entombing structure can be expected to last many half-lives of the most objectionable long-lived isotope, then ENTOMB becomes a viable alternative because of the reduced occupational and public exposure to radiation. ENTOMB does, of course, contribute to the problems associated with increased numbers of sites dedicated for very long periods to the containment of radioactive materials.

2.5 RESIDUAL RADIOACTIVITY LEVELS FOR UNRESTRICTED USE OF A FACILITY

Decommissioning requires reduction of the radioactivity remaining in the facility to residual levels which are considered acceptable for permitting release of the facility for unrestricted access and for consequent NRC license termination. Preliminary NRC staff views on setting appropriate levels have recently been presented in several documents.(4, 5, 6)

2.5.1 Existing Regulations and Guidance

As set forth in the Energy Reorganization Act of 1974, the Environmental Protection Agency (EPA) has the responsibility for establishing radiation dose standards for the protection of the public health and safety. Thus, the EPA has the responsibility for establishing the criteria for residual radioactivity limits considered safe for decommissioning a nuclear facility to unrestricted access but has not yet instituted this criteria and is not scheduled to do so until 1984. Existing NRC and EPA guidance and regulations are not specific enough. License termination of nuclear facilities that have been decommissioned for unrestricted access have been done on a case-by-case basis. The primary NRC regulation dealing with this issue is 10 CFR Part 20, "Standards for Protection Against Radiation" which has applicability to decommissioning as well as to operating a nuclear facility. The standard for the maximally exposed individual is given in terms of a contaminant whole-body radiation dose rate (mrem/year) limit not to exceed 500 mrem/year and for the general public this limit is 170 mrem/year. Both of these limits are to be applied using the ALARA (As Low As Is Reasonably Achievable) principle, i.e., the dose rate should be reduced to a level below these limits to a value that is ALARA.

More specific NRC guidance on what such ALARA values are is contained in Regulatory Guide 1.86 (included in Ref. 6) and gives the currently acceptable surface contamination levels for release of a nuclear reactor facility for unrestricted use. These levels are given in units of disintegration per minute per 100 Cm^2 and are for surface contamination with specific nuclides. For other nuclear facilities, guidance for release is given in an NRC staff position paper (included in Ref. 6) entitled "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source or Special Nuclear Material". The acceptable surface contamination levels are the same as those in Regulatory Guide 1.86, except that the table in the NRC staff guideline has an extra footnote prescribing acceptable dose rates measured at 1 cm from the surface. Neither Regulatory Guide 1.36 nor the staff position paper deal with activation products or volumetric contamination. Also, neither relates the surface contaminant concentrations to annual dose rates, nor justifies that the values presented are ALARA.

For operating reactors 10 CFR 50 Appendix I presents design objectives and limiting conditions for operation to ensure that reactor effluents are ALARA. For whole-body dose, these Appendix I ALARA levels are 3 or 5 mrem/year to an individual in an unrestricted area from all pathways of exposure for either the water or air effluent pathways. It should be noted that the limits specified can be satisfied for compliance through use of appropriate pathway modeling of estimated reactor effluents. Actual field measurements of radiation dose corresponding to the ALARA levels are not required.

The EPA has set whole-body radiation dose limits of 25 mrem/year per person as a result of exposure to planned discharges of radioactive materials, radon and its daughter excepted, from all uranium fuel cycle operations combined (40 CFR 190). Again, use of appropriate pathway modeling of effluent source terms is all that is required for compliance.

2.5.2 Residual Radioactivity Limit Requirements

There are two basic requirements in selecting residual radioactivity levels which are considered acceptable for releasing a decommissioned facility for unrestricted use. The first is that the level must be considered safe and consistent with existing regulations and that it must be low enough to comply with the ALARA concept. The second is that the chosen level must be verifiable through actual detailed survey measurements of the facility and site. The verification survey associated with this level, in accordance with the ALARA principal, must be within reasonable bounds regarding state of the art detection methodology and costs. Therefore, the residual radioactivity limit should be based on a careful weighing of the costs versus the benefits, so as not to cause potential public health and safety problems after the facility is released for unrestricted use. Because of the need for decommissioning planning and potential implementation of regulations in the near future, the NRC needs to set residual radioactivity limits prior to the time of formal issuance of criteria by EPA. In discussions with EPA staff relative to providing preliminary guidance for NRC in establishing these limits, consistent with eventual EPA requirements, the following conclusions, within the framework of the ALARA concept, were reached:(4)

(1) potential doses from decommissioned facilities should be less than those from operating ones,

(2) doses (whole body equivalent) above about 5 mrem per year are probably unacceptable,

(3) justification would be required for doses more than 1 mrem per year, and

(4) a plan for complying with these criteria could utilize realistic rather than conservative pathway analysis.

In item (4), the intent is to use a dose pathway analysis that provides a realistic assessment of potential dose to an individual. Realistic analyses involve recognition that occupancy is less than 100 percent of the time, that the source of sustenance is not limited only to the decommissioned site, that self shielding reduces the dose and that resuspension is decreased by weathering as a function of time. Such assessment takes consideration of current population living patterns, with some conservatism for individual or localized group deviations. The overly conservative case that is usually used for such analysis for a few hypothetical individuals who may have peculiar dose potential situations, is not used in the realistic assessment of potential doses. Thus, the use of realistic assessment methodology attempts to equitably deal with potential risk to public health and safety to an individual taking account of societal considerations of risk and cost.

It should be noted that the population at risk from a decommissioned facility is much less than from an operating one where a source of continuous radioactive effluent exists. The effects of such effluent is generally considered out to a 50-mile radius from the source. Such an effluent would be negligible for a decommissioned facility. For the generic site for a decommissioned facility described in Chapter 3 of this report, the site occupies about only about 1000 acres. As an example of an evaluation of the risk to a population from a decommissioned facility, consider a situation in which after decommissioning is complete, a housing community is constructed on the site on 1/4 acre lots. For an average family of 5 per home, this would be a community of 20,000 people. This is a small risk community compared to risk communities exposed to operating facilities which are usually made up of between several hundred thousand to millions of people.

In evaluating the risk to the population from the decommissioned facility, consideration is given the BEIR committee results which indicate that a 1 rem dose is equivalent to a risk of 10^{-4}. Thus, the 5 mrem dose from the decommissioned facility results in a risk of 5×10^{-7} (1 in 20 million).(5) Generally, evaluation of risk exposure has resulted in a risk of 1 in a million being considered acceptable.(5) The risk that the population is exposed to is probably less than that associated with a 5 mrem dose because, unlike the source of contamination for an operating plant, the source of contamination at a decommissioned facility will decrease, through radioactive decay, decreasing bio-availability and lowered resuspension of radionuclides, consequently reducing the dose and associated risk over time. In addition, the risk to the population is probably lower because the actual dose level in most areas of the site is probably lower than the level at which the instruments can certify.

2.5.3 Implementation of Objectives

As can be inferred from earlier discussion, a meaningful representation of a residual radioactivity limit is in terms of dose, which has a quantitative relationship to cancer risk to the exposed population. Dose limits have usually been applied to a limiting critical organ at risk for a limiting specific radionuclide and pathway. This makes comparative risk for different facilities difficult to deal with. It is desirable to reflect the dose result through a single number rather than through several limiting organ doses. Use of ICRP-26 makes such a technique possible in that it allows summation of risks from all organs into a whole-body dose equivalent(5) (i.e., a summation of a normalized risk weighted distribution of organ doses). Thus, in further discussions of dose, only whole body dose equivalent will be used.

A dose representation is generic in nature and covers all nuclear facilities under consideration regardless of their respective radionuclide contaminant distribution and associated dose pathway considerations. For actual measurements, however, a translation of such dose limit into nuclide specific surface or volumetric concentrations is required.

Use of appropriate realistic dose pathway analysis (including receptor useage) provides the method for converting a selected dose value to an equivalent radionuclide specific contaminant concentration (based on existing facility spectra analysis). For the facilities considered in this EIS, for planned decommissioning, appropriate spectra analysis should lead to only a few nuclides being major dose contributors for a specific facility type (e.g., for a reactor, the dominant nuclides are ^{60}Co and ^{137}Cs). The specific details of a dose methodology for performing such calculations through the use of a computer code has recently been completed.(7) Use of this code and appropriate realistic usage factors (i.e., residence occupany time, outside exposure time, resuspension, etc.) will be employed in revising Regulatory Guide 1.86 to adequately reflect specific measurement requirements for the limiting dose value selected.

Preliminary use of this dose methodology code and estimated realistic usage factors for the case of a PWR facility was recently employed by Oak Ridge National Laboratory (ORNL) for estimating requirements for a terminal site certification survey.(8) ORNL is currently establishing a data base for the terminal certification for all facilities considered in this EIS in terms of available instrumentation, procedures, effort and costs. In preliminary results for the PWR, certification surveys at realistic dose values 1 5 and 25 mrem/year were considered. It was indicated that a survey for the 1 mrem/year value was difficult and costly to achieve; a survey for the 5 mrem/year value was considered to be well within technical capability and could be done for a cost of approximately $250,000 (i.e., less than about 0.6% of estimated PWR decommissioning costs); and a survey for the 25 mrem/year value is estimated to cost not much less than that for 5 mrem/year (about $225,000). Thus for the PWR case, as considered in the preliminary results, a residual radioactivity level corresponding to 5 mrem/year or less would be justifiable on the basis of survey costs.

There should be no significant additional decontamination effort required as a result of the termination survey, perhaps only cleanup of a few hot spots indicated by the survey. This is because the extensive efforts required to decontaminate the highly contaminated facility to low radoactivity levels will result in residual radioactivity levels well below the limits which permit unrestricted release of the facility. It is also the case because spot surveys will be carried out periodically during the decommissioning period so that at the time of the termination survey the licensee is confident that decontamination efforts have achieved the acceptable residual radioactivity levels in most instances. Thus, because there should not be significant additional decontamination necessary after completion of the termination survey, the major cost and effort expected for verifying the required residual radioactivity levels for unrestricted facility use should come from the certification survey. As indicated above for the PWR example, these survey costs are expected to be a small fraction of the total decommissioning cost, and thus the effort to certify that the facility is available for unrestricted use should not add significantly to the overall decommissioning cost.

In addition, cost-benefit considerations are involved in the evaluation of the extent of facility decontamination necessary to reduce radioactive contamination to levels considered acceptable for releasing the facility for unrestricted use. As is discussed by PNL in NUREG/CR-0130,(9) and in NUREG/CR-0278,(10) and as is also inherent in the reports prepared by PNL for the other nuclear facilities discussed in this EIS, the cost of decontamination of a facility and hence its decommissioning, is essentially independent of the level to which it must be decontaminated as long as that level is in the range of 1 to 25 mrem/yr to an exposed individual. This is because, as indicated above, it is expected that the extensive efforts required to decontaminate the highly contaminated facility to low radioactivity levels will result in residual radioactivity levels well below the limits to permit release of the facility for unrestricted use. An additional cost-benefit consideration is that related to decontamination of rooms which are mildly contaminated with radioactivity. Most rooms should not be mildly contaminated with radioactivity in excess of levels which are acceptable for unrestricted facility use since it is assumed that good housekeeping and ALARA practices will be used during facility operations to control the spread of contamination. In areas where there is mild contamination, techniques such as having previously painted surfaces should make decontamination easier and less costly. A source of data for the evaluation of cost for decontamination of mildly contaminated rooms is in NUREG/CR-1754(11) which evaluates decontamination of a number of specific components. As an example, for a hot cell contaminated with Cs-137, the manpower needed for decontamination would be approximately 5 man-days and the associated costs would be approximately $5,000. Costs for decontamination of other specific components would be about the same order. These costs for decontamination of specific mildly contaminated components are small in comparison to the overall decommissioning costs. Therefore, based on the above discussions, while cost-benefit is a consideration, it is not expected to have a major impact on the GEIS results concerning reactor or most nonreactor decommissionings. Cost-benefit may be a consideration in the removal of ore piles at non-fuel-cycle ore processing facilities where costs of disposal of the ore is very large.

Due to the variety of facility types and radionuclides involved it is not feasible to set a single dose limit that would be valid under all conditions for all facilities. It is necessary to assess the radiological impact in terms of the radionuclides and pathways involved and the costs and benefits which result. Based on these considerations and on consideration of the residual radioactivity limits discussed in this section, the following recommendations are made:

(1) A residual radioactivity level for permitting release of a nuclear facility for unrestricted use should be ALARA. Guidance in establishing such a limiting level is best expressed in terms of a value which bounds the dose for the majority of facilities discussed in this report. This value has been determined to be 10 mrem/yr whole-body dose equivalent, but could be lower than that for specific facilities. The 10 mrem/yr limit is chosen recognizing that it may be impractical and unnecessary in some cases to meet the 5 mrem/yr limit previously mentioned (in conclusion 2 of Section 2.5.2) because of cost-benefit considerations and problems in detectability, sampling, and/or exposure patterns. Further discussion with EPA has indicated that the 10 mrem/yr limiting value would not be considered unreasonable. In all cases, a dose limit above 1 mrem/yr would require justification. For a few situations, it is expected that residual limits will be outside the bounds of the 1 to 10 mrem/yr range. For these special situations, case-by-case analysis in terms of cost and benefit effectiveness will be required to establish appropriate limiting levels.

(2) Such dose rates and associated allowable contamination levels should be based on realistic dose assessment methodology.

By making use of the realistic pathway analysis, the choice of these residual radioactivity levels are consistent with current EPA(4) and previous NRC regulatory guidance (Regulatory Guide 1.86 concentration values converted to dose) and with the former AEC guidance and of various decommissionings of AEC facilities. As indicated in Section 2.5.2, this realistic analysis is based on such factors as occupancy, shielding, radioactive decay, weathering, ingestion pathways, and resuspension. Consideration of these factors can be applied in order to convert the radiation levels as measured by the terminal radiation survey to a dose that a member of the public would realistically be expected to be exposed to from the decommissioned nuclear facility.

In making this evaluation, a situation is considered in which a reactor has been decommissioned, a certification survey of the reactor and its site has been completed and the facility and site are being considered as to their acceptability for being released for unrestricted use. In making the determination of acceptability, the NRC must consider the dose which the public may receive as a result of exposure from the decommissioned facility. Several potential uses of the decommissioned facility and its site are considered to determine which would be the most limiting in terms of estimated dose to the public. These potential uses include industrial use of the facility, farming of the site, recreational use of the site, and residential use of the site. The limiting case is considered to be a housing development that might be constructed on the site. It is assumed that wood frame houses are constructed in the development. The principal nuclides involved in the dose analyses are Co-60 and Cs-137 and the principal pathway is direct exposure to these radionuclides assuming they have been deposited on the ground during the operating lifetime of the facility. At the time of the certification survey, it is assumed that the measurement of the site showed an exposure level of no greater than 5 μr/hr which is a value considered to be consistent with measurement sensitivities given in Regulatory Guide 1.86.

In the analysis of the dose to the exposed population in the housing development, several factors are considered in estimating the dose which they would realistically be expected to receive from radiation levels corresponding to those of the certification survey.(12) These factors, which are dose reduction factors, are occupancy and building shielding, radioactive decay, and shielding due to excavation and grading of the site. Based on parameters given in Regulatory Guide 1.109(13) and WASH-1400,(14) the combined factor for the reduction of dose due to building shielding and occupancy is estimated to be 0.5. This considers the amount of time an individual would spend at home and the shielding of the building. Radioactive decay occurs after the certification survey and prior to the occupation of the housing development, a time period which is estimated to be 2 years (1 year for administrative actions after the survey, and 1 year for sale of the land and housing construction and sales). With this time period, the reduction factor for radioactive decay would be 0.85. Finally, it was considered that the construction of housing would result in movement of earth on the site for grading, excavation, road paving, etc., and this results in shielding of radioactivity in the surface soil. There is not an adequate existing model for estimating a reduction factor for this activity primarily because for operating reactors the more important case is exposure at existing houses. ORNL will be developing a reasonable model for this parameter as well as other parameters for use in this analysis. However, a simple and reasonable model is to assume that the excavation soil from house basement construction is spread over the surface of the individual lots. This results in a reduction factor of 0.4. This does not take into account such activities as movement of the earth for grading purposes, for clearing of the site, for road construction, etc., which may result in as much reduction due to shielding as the excavation. Hence, the reduction factor of 0.4 is considered reasonable.

Considering all of these reduction factors combined, the realistic analyses of the dose to a member of the population, exposed to radiation levels corresponding to those of the certification survey, would be approximately 7 mrem/yr. (It is expected that this value will be lower when detailed development of realistic parameters is complete). This value is below the 10 mrem/yr value discussed above as being acceptable for releasing the site for unrestricted use.

In addition to the evaluation for reactors, nonreactor facilities have also been evaluated in order to convert the radiation levels as measured by the terminal radiation survey to a dose that a member of the public would realistically be expected to be exposed to from a decommissioned nuclear facility. As in the case of the reactor, a situation is considered in which the facility has been decommissioned, a certification survey of the facility and its site has been completed, and the facility and site are being considered as to their acceptability for being released for unrestricted use. Also as in the case of the reactor, several potential uses of the decommissioned facility and its site are considered. For nonreactor facilities, factors important in the evaluation include resuspension of aged radionuclides, occupancy, bioavailability, food pathway factors, and shielding. Based on these factors, the limiting case in terms of estimated dose to the public for nonreactor facilities is a housing development that might be constructed on the decommissioned facility site. At the time of the certification survey it is assumed that the measurement of the site showed an exposure level consistent with measurement sensitivities given in Appendix A of NUREG-0436.(6) Based on an analysis(15) similar to that for reactors as discussed above, the realistic analysis of the dose to a member of the population, exposed to radiation levels corresponding to those of the certification survey, would be within the 1-10 mrem/yr range.

2.6 FINANCIAL ASSURANCE

The primary objective of the NRC with respect to decommissioning is to protect the health and safety of the public. An important aspect of this objective is to assure that, at the time of termination of facility operations (including premature closure of the facility), adequate funds are available to decommission the facility resulting in its release for unrestricted use. Assurance of this availability of funds ensures that decommissioning can be accomplished in a safe and timely manner and that lack of funds does not result in delays in decommissioning that may cause potential health and safety problems for the public. The need to provide this assurance arises from the fact that there are uncertainties concerning the availability of funds at the time of decommissioning. These uncertainties are of two general types. The first is that the financial solvency of a particular organization is difficult to predict several years into the future when decommissioning of a specific facility is likely to occur. The second type of uncertainty is that, potentially, a facility could be forced to shut down prematurely.

The nuclear facility licensee has the responsibility for completing decommissioning in a manner which protects public health and safety. Satisfaction of this objective requires that the licensee provide a high degree of assurance that adequate funds for performing decommissioning will be available at the end of facility operation. Because of the possibility of premature closure of the facility, financial assurance provided by the licensee should also contain a mechanism enabling funds for the full cost of decommissioning to be made available at any time during facility operation.

2.6.1 Present Regulatory Guidance

Present regulatory requirements concerning the degree of financial assurance required of a licensee are not specific enough. 10 CFR 50.33(f) and 10 CFR 50, Appendix C require the applicant for a production or utilization facility operating license to demonstrate financial capability both to operate the facility and to shut it down and maintain it safely. 10 CFR 50, Appendix F requires the applicant for a fuel reprocessing plant operating license to demonstrate his financial qualifications "to provide for removal and disposal of radioactive wastes during operation and upon decommissioning." These regulations do not require that funds actually be available at the time they are needed, nor do they provide enforcement procedures. Also, there is no provision for decommissioning in the event of premature closure of the facility.

For fuel cycle facilities, the NRC staff is requiring as a license condition that new major fuel cycle applicants and applicants for license renewal provide decommissioning plans and financial arrangements for paying these expenses.

2.6.2 Implementation of Financial Assurance Requirements

In providing the high degree of assurance necessary that funds are available for decommissioning, there are several possible financing mechanisms, outlined below, which are available to applicants and licensees. The many different types of nuclear facilities present a wide diversity in the cost of decommissioning, in the risk that decommissioning funds might be unavailable, and in the licensees' financial situations. This diversity necessitates that the NRC allow a wide latitude in the implementation of these financing mechanisms. For example, the situation for a reactor, where state utility commissions regulate retail rates and the Federal Energy Regulatory

Commission regulates wholesale rates and where decommissioning costs are high, is significantly different than the situation for a small non-fuel-cycle facility which is a private business organization and for which decommissioning costs are lower.

A preliminary NRC staff analysis(16) for providing guidance as to what funding mechanisms provide adequate assurance has led to the following major classification of funding alternatives (used singly or in combination):

(1) Prepayment - Cash or other liquid asset that will retain their value for the projected operating life of the facility should be deposited into an account prior to facility startup. This account would be segregated from other company funds.

(2) Decommissioning insurance, sureties, bonds, letters of credit and lines of credit - Insurance, most likely for the larger facilities, which could potentially provide for all decommissioning expenses, including potential premature decommissioning, or insurance to cover only costs of premature decommissioning may be used. The surety bond or credit mechanisms guarantee that the decommissioning costs will be paid should the bond purchaser default. The bond holder still must provide funding for decommissioning through some other method. It appears questionable that surety bonds of the size necessary and for the time involved with power reactors will be available. However, they appear to be available for facilities that involve smaller costs and periods. The contractual arrangement guaranteeing the suretys must include a provision for noncancelability, preferably over the projected operating life of the facility. Sufficient time for NRC notification of imminent surety cancellation must be guaranteed, in any case, to allow for termination of operating license and required decommissioning. Such forced decommissioning would result if the NRC determined that a loss of surety by the licensee resulted in an unacceptable financal assurance condition. It should be kept in mind that suretys would only be called if at the time of cessation of facility operation or impending surety loss, licensee decommissioning funds were inadequate or unavailable.

(3) Sinking Funds - The sinking fund or funded reserve approach requires that a prescribed amount of funds, subject to periodic revision, be set aside annually in an account, segregated from other company funds, such that the fund plus accumulated interest would be sufficient to pay for decommissioning costs at the time of termination of facility operation. The fund could be invested in high-grade corporate securities, in State or municipal tax-free securities, in Federal debt obligations, or other assets. The weakness of the sinking fund approach is that in the event of premature closure of a facility the decommissioning fund would be insufficient. Therefore, the sinking fund would have to be supplemented by decommissioning insurance or other mechanisms of item (2), which would pay the difference.

Another funding mechanism which has drawn considerable interest and discussion, especially among electric utilities, is that referred to as internal reserve or unsegregated sinking fund. This mechanism usually uses negative net salvage value depreciation which allows estimated decommissioning costs to be accumulated over the life of the facility. In this mechanism, the funds are not segregated from the utility's assets, rather they are invested in utility plant assets and, at the end of life, bonds are issued against such plant assets and the funds raised are used to pay for decommissioning. Such a mechanism is generally favored by utilities because it is considered to be less expensive in terms of net present value than the options listed above, although, as discussed below, whichever funding mechanism is used should not have a significant impact on the revenue requirements. The problem with the internal or unsegregated funding method is the lack of assurance that funds will be available to pay for decommissioning. Because this method depends on financing internal to the licensee, the unfunded reserve is vulnerable to any event or situation that undermines the financial solvency of a utility. A utility with serious financial troubles would have difficulty raising capital against its decommissioning reserve. In addition, in the event of financial distress of a utility, an internal reserve may not be available to pay for decommissioning costs, but may have to be paid instead to satisfy claims of superior creditors. Under the NRC's responsibility to protect public health and safety by assuring that funds are available for a safe decommissioning, the internal reserve would be considered an adequate funding mechanism only if it were supplemented by substantial additional financing mechanisms (such as insurance or some other surety arrangements) that overcome the assurance deficiencies.

Whatever funding mechanism is used, its use requires an estimate of the cost required for decommissoning a facility. Such cost should be included in a financial plan submitted by an applicant prior to facility commissioning. Because the cost of decommissioning various nuclear facilities is not well established, due to limited experience, the Battelle PNL reports mentioned in this EIS can be used for preliminary cost estimating. These reports contain sensitivity analysis to include licensee situations that may differ from the reference facility decommissioning cost estimates presented.

As information on decommissioning costs become more definitive in time, due to technology improvements, enhanced decommissioning experience, and inflation/deflation cost factors, a licensee's financial plan and funding mechanism should be updated. In this way, it is expected that the decommissioning fund available at the time of facility shutdown will not differ significantly from actual costs of decommissioning.

It is difficult to accurately estimate what the projected costs for the various funding mechanisms will be at the time of decommissioning. There are uncertainties relating to inflation/deflation, rates of return, tax issues, method of fund collection, etc. which make actual decommissioning cost estimates speculative.(16) In any case based on Battelle cost analyses presented in this EIS, it is reasonable to estimate that current decommissioning costs are less than 10% of present worth commissioning costs. For example, for the generic PWR 1175 MWe reactor, decommissioning costs have been estimated at approximately $40 million. This results in a cost of a few tenths of a mill (0.1 cent) per kilowatt-hour when averaged over the expected 30-year reactor operating life. The $40 million cost, while not insignificant, is only a small amount compared to PWR operating capital, perhaps comparable to the cost of a full core reload. Furthermore, whichever funding mechanism is used should not have a significant impact on the cost to consumers. One study(17) has estimated that the difference in cost between the various funding mechanisms would result in less than a 1% difference in the total bill of a respresentative utility customer.

An additional point that must be considered is the cumulative impact that the financial mechanisms proposed in this section will have on the nuclear industry and on the financial market. For the larger facilities involved, such as reactors and other large nuclear facilities, a large requirement on the capital market might be involved if all the facilities used the prepayment method of financing. One study(16) has estimated that approximately $3.5 billion would be required for reactors currently licensed to operate if they all used the prepayment method. Since the capital raised for decommissioning would not contribute to increasing revenue, this situation might result in an increase in the cost of capital to the utilities and other organizations involved. However, several factors tend to mitigate the problem. One is that, placed in the perspective of the percentage of total capital requirements of electric utilities, obtaining funding at facility startup should not prove unmanageable. Another is that funding for the various facilities could be spaced over time so as not to strain capital markets. For example, implementation of funding might begin with those plants closer to end of life and then move on to those plants more recently commissioned. Finally, since many of the plants might choose the sinking fund method, this would result in less of a burden on the capital market. For the smaller facilities with smaller decommissioning costs, the strain on the capital market should not be so great. However, there may be a large administrative burden in providing funding mechanisms for the large number of non-fuel-cycle facilities. Hence, for these types of facilities, a comparatively simple system of funding, for example, tied to the issuance of a license, would probably be less burdensome and more cost-effective. Thus, implementation of funding mechanisms can be done in such manner that the impacts are manageable.

In summary, current regulations require that at the time of facility licensing, as a matter of protection of public health and safety, an applicant should be financially sound. This objective of protecting the public health and safety also extends to the need for providing funds for decommissioning. Since the cost of decommissioning is only a small fraction of the cost of commissioning, there should not be any significant financial burden on the applicant in providing a funding mechanism for decommissioning costs either through prepayment, surety bonds, a sinking fund, insurance or some combination thereof.

2.7 MANAGEMENT OF RADIOACTIVE WASTES AND INTERIM STORAGE

Decommissioning of a nuclear facility results in the generation of radioactive waste which must be disposed of at waste disposal sites. These wastes include equipment and structures made radioactive both by neutron activation and by radioactive contaminants, include radioactive wastes resulting from chemical decontamination of the facility, and include miscellaneous cleaning equipment. These wastes fall into one of the following five major classes of nuclear waste as defined by the March 1979 Report to the President by the Interagency Review Group (IRG) on Nuclear Waste Management:(18)

1. High-level wastes (HLW) are either intact fuel assemblies that are being discarded after having served their useful lives in a nuclear reactor (spent fuel) or the portion of the wastes generated in the reprocessing of spent fuel that contain virtually all of the fission products and most of the actinides not separated out during reprocessing. These wastes are being considered for disposal in geologic repositories or by other technical options designed to provide long-term isolation of the wastes from the biosphere.

2. Transuranic (TRU) wastes result predominantly from spent fuel reprocessing, the fabrication of plutonium to produce nuclear weapons, and, if it should occur, plutonium fuel fabrication for recycle to nuclear reactors. TRU waste is currently defined as material containing more than 10 nCi of transuranic activity per gram of material. These wastes would be disposed in a similar manner to that used for high-level waste disposal.

3. Low-level wastes (LLW) contain less than 10 nCi of transuranic element contaminants per gram of material, or they may be free of transuranic contaminants, require little or no shielding, and have low, but potentially hazardous, concentrations or quantities of radionuclides. Low-level wastes are generated in almost all activities involving radioactive materials and are presently being disposed of by shallow land burial.

4. Uranium mine and mill tailings are the residues from uranium mining and milling operations which contain low concentrations of naturally occurring radioactive materials. The tailings are generated in very large volumes and are presently stored at the site of mining and milling operations.

5. Gaseous effluents are released into the biosphere and become thereby diluted and dispersed.

These definitions do not adequately define the highly activated reactor components that will require disposal during decommissioning. Present practice is to bury these components in slit trenches or in special areas in low-level waste burial grounds.

The IRG report lists the quantities of existing wastes, including spent fuel, as shown in Table 2.6-1. Quantities of defense wastes are also given for perspective.

TABLE 2.6-1. Quantities of Existing Radioactive Wastes (1977)

High-Level Waste	
Commercial	2 300 m^3
Defense	266 000 m^3
Transuranic Waste	
Commercial	123 kg
Defense	1 100 kg
Spent Fuel Discharged from Commercial Reactors	2 300 MTHM
Buried Low-Level Waste	
Commercial	447 000 m^3
Defense	1 439 000 m^3
Uranium Mill Tailings	127 000 000 MT

The IRG report also points out that an operating 1000 MWe reactor will generate approximately 25.4 MTHM (9.4 m^3) of spent fuel each year and 1300 m^3 of low-level waste each year. When multiplied over the 40-year operating lifetime of the plant, these values can be compared to the 11 m^3 of activated material and 17,900 m^3 of low-level waste resulting from DECON of a PWR of similar size, and it can be seen that decommissioning will generate an appreciable fraction of the low-level waste generated by a PWR over its lifetime. However, in any given year, the quantity of waste from all operating reactors will considerably exceed that generated from those facilities being decommissioned. The IRG expects that low-level wastes generated in 1980 from commercial nuclear fuel cycle activities will total 81,000 m^3 and that low-level wastes from commercial non-fuel-cycle activities will total 28,000 m^3. Hence, problems in waste disposal capacity will be the result primarily of operating nuclear facility waste inputs rather than decommissioning waste inputs. The following is a discussion of some current problems in this area.

At the present time only low-level waste burial grounds and uranium mill tailings piles exist. There are no deep geologic disposal facilities for spent fuel, high-level wastes, or highly activated components. Commercial spent fuel is accumulating in reactor spent fuel storage pools. Commercial high-level waste (2 300 m^3) is presently in interim storage at West Valley, New York. The small amount of commercial TRU waste is distributed among five locations.

Pending implementation of the IRG report recommendations and construction of permanent high-level waste and TRU waste disposal facilities, interim storage facilities may have to be constructed. Independent spent fuel storage installations would be one way of storing spent fuel from reactors on an interim basis. These facilities consist primarily of large water-filled pools similar to reactor spent fuel storage pools. Some high-level and TRU wastes could also be stored in the same manner. A possible facility and its decommissioning are discussed in Section 12.

Interim storage of low-level waste may also be required in the case of large volumes of material (see Section 14) or in case permanent facilities are unavailable, as was the situation briefly in the fall of 1979. Reasonable volumes of waste can be temporarily placed on concrete slabs in suitable containers in covered sheds with fencing and minimum security. Low-level wastes from other sources can be sealed in prescribed containers and also placed on concrete slabs in sheds with minimum security. Small numbers of waste containers can be placed briefly in almost any properly secured room or building, but only as a temporary expedient.

Hence, based on the above discussion, at the time of decommissioning of a nuclear facility, contingency provision should be provided by the licensee for interim storage of decommissioning wastes if permanent waste disposal capacity is unavailable.

2.8 SAFEGUARDS

During the initial stages of decommissioning, the same safeguards measures may be required that are required while the facility is operating. During the actual decommissioning, levels of special nuclear material in the facility should decrease as a result of cleanup of the facility. In the case of DECON, decreasing levels of safeguards measures should be continued until the quantity of special nuclear material is reduced below safeguards levels, at which time safeguards measures can be discontinued. Regulations defining required procedures and safeguard levels are found in 10 CFR Part 70 Special Nuclear Materials and 10 CFR Part 73 Physical Protection of Plant and Materials. In the case of SAFSTOR, depending on the quantity of special nuclear material as compared to the safeguards levels, continuous manned security may be required or may be replaced by continuous remote monitoring of intrusion, fire, and radiation alarms during the continuing care period. Immediate response is, of course, required in case any alarm is activated. Engineered barriers, such as fences and high-security locks, are maintained and inspected regularly. Deferred decontamination requires similar safeguards provisions as are required during DECON depending on the quantity of special nuclear material remaining at that time. The long-term care period of ENTOMB requires remote monitoring of intrusion, fire, and radiation alarms and engineered barriers if special nuclear material quantities are above safeguard levels.

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

**Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

***Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service.

3.0 AFFECTED ENVIRONMENT - GENERIC SITE DESCRIPTION

This section describes the characteristics of the sites used as bases for the decommissioning studies of the nuclear facilities discussed in this document. Each facility, with the exception of non-fuel-cycle nuclear facilities, is considered to be located on a reference site. The site described is considered to be representative of the site of a large nuclear installation. Based on the analyses done in Sections 4 through 14 of this EIS, it was found that, while some details may vary from installation to installation, these differences are not expected to have any major impact on the results of the study. The generic fuel cycle facility site is described in Section 3.1.

3.1 FUEL CYCLE FACILITY SITE

A reference environment was developed to aid in assessing the public safety and potential environmental effects of decommissioning nuclear facilities by various alternative methods. The meteorology parameters and population distributions were taken from the ALAP Study(1) for a river site in the year 2000. The ecological information was derived from the environment of one operating nuclear reactor.(2) The remainder of the information was obtained from a variety of sources or developed specifically for these studies, and is felt to be representative of potential sites for fuel cycle facilities.

Individual features of any specific nuclear fuel cycle facility will vary slightly from those of a generic site. However, it is believed that use of a generic site will result in a more meaningful overall analysis of potential impacts associated with decommissioning nuclear fuel cycle facilities. Site-specific assessments will be required for the safety analysis and the environmental report submitted with the application for license modification prior to decommissioning a specific facility.

The generic fuel cycle facility site occupies 470 hectares (1160 acres) in a rectangular shape of 2 km (1.24 miles) by 2.35 km (1.46 miles). A moderate sized river runs through one corner of the site. The site is located in a rural area that has relatively low population density. Higher population densities are located at distances of 16 to 64 km (10 to 40 miles), and gradually reducing population densities are encountered out to 177 km (110 miles). The closest moderately large city, population 40,000, is about 32 km (20 miles) distant. The closest large city, population 1,800,000 is about 48 km (30 miles) away. The total population in a radius of 80 km (50 miles) is 3.52 million.

The plant facilities are located inside a 12-hectare (30-acre) fenced portion of the site. The minimum distance from the point of plant airborne releases to the outer site boundary is 1 km. Of the area surrounding the site, about 80% of the land is used for farming.

The relatively clean river flowing through the site has an average flow rate of 1,420 m^3/sec (50,000 ft^3/sec). The river is used for irrigation, fishing, boating and other aquatic recreational activities, and is a source of drinking water for the larger communities. Large supplies of flowing ground water exist at modest depths around the site. This water is widely used for drinking and irrigation.

The reference site occupies a relatively flat terrace that has a low bluff forming one bank of the river. Young soils cover the old basement rocks in the area. This site is in a relatively passive seismic area and is located at an elevation above the estimated maximum probable flood level.

The climate at the site is typical for internal continental areas. It has wide temperature variations and moderate precipitation. Meteorology used in this study is an average taken from 16 nuclear reactor sites.

Less than 20% of the land around the site is covered with pristine vegetation. The original vegetation was primarily a climax deciduous forest. A number of species of migratory birds are present in the area, as well as some annual birds. A number of mammals occupy the general area.

The site is slightly contaminated with radioactive material as a result of deposition from the release of normal operating effluents over the operating lifetime of the facility. It is expected that any accidental releases of radioactive material will be cleaned up immediately following the event. The individual site contamination estimates are based on the predicted normal operating releases of gaseous effluents from the specific type of facility.

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4.0 PRESSURIZED WATER REACTOR

A pressurized water reactor (PWR) is a facility for converting the thermal energy of a nuclear reaction into steam to drive a turbine-generator and produce electricity. The conversion is accomplished by heating water to a high temperature and pressure in the reactor pressure vessel, using the pressurized hot water to produce steam in the steam generator, and driving the turbine-generator with the steam.

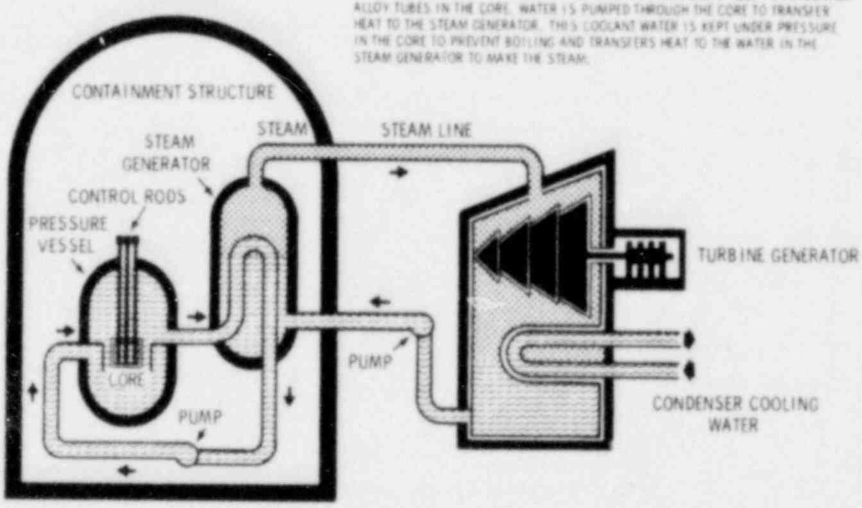
The generic site for the reference 1175-MWe PWR is described in Section 3.1. The specific site for a reactor is chosen on the basis of operational and regulatory criteria, some of which are appropriate to decommissioning as well as to reactor construction and operation. For example, transportation access, water supply, and a skilled labor supply are required for construction and operation, and are also necessary for decommissioning. Usually, however, the most suitable decommissioning alternative will not depend upon the generic site description or upon specific siting considerations. Rather it will depend on such factors as desirability of terminating the license, land use considerations at the time of decommissioning, occupational radiation exposures, and costs. The choice of decommissioning alternative may also depend upon whether or not the facility must be decommissioned before normal retirement age because of premature closure. In any event the particular alternative chosen will depend almost entirely upon circumstances at the time of decommissioning, rather than upon earlier siting considerations.

Much of what follows is based on the NRC-sponsored Pacific Northwest Laboratory (PNL) study on the technology, safety and cost of decommissioning a PWR.(1)(2) In this study, PNL selected the Portland General Electric Company's 1175-MWe Trojan Nuclear Plant at Rainier, Oregon, as the reference PWR and assumed it to be located on a generic site typical of reactor locations. PNL then developed and reported information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life. Also, as part of an addendum(2) to this study,(1) PNL did a sensitivity study to analyze the effect that varying certain parameters might have on the conclusions in the original study regarding doses and costs of decommissioning. The parameters which were varied in the addendum included reactor size, degree of radioactive contamination, decommissioning alternatives, etc.

4.1 PWR DESCRIPTION

The major components of a PWR are a reactor core and pressure vessel, steam generators, steam turbines, an electric generator, and a steam condenser system (Figure 4.1-1). Water is heated to a high temperature under pressure inside the reactor and is then pumped in the primary circulation loop to the steam generator. Within the steam generator, water in the secondary circulation loop is converted to steam that drives the turbines. The turbines turn the generator to produce electricity. The steam leaving the turbines is condensed by water in the tertiary loop and returned to the steam generator. The tertiary loop water then flows to cooling towers where it is, in turn, cooled by evaporation. The tertiary loop is open to the atmosphere, but the primary and secondary cooling loops are not.

Buildings or structures associated with the reference PWR include 1) the heavily reinforced concrete containment building, which houses the pressure vessel, the steam generators, and the pressurizer system, 2) the turbine building, which contains the turbines and the generator, 3) the cooling towers, 4) the fuel building, which contains fresh and spent fuel handling facilities, the spent fuel storage pool and its cooling system, and the solid



A NUCLEAR POWER REACTOR PRODUCES STEAM TO DRIVE A TURBINE WHICH TURNS AN ELECTRIC GENERATOR. INSTEAD OF BURNING FOSSIL FUEL, A REACTOR FISSIONS NUCLEAR FUEL TO PRODUCE HEAT TO MAKE THE STEAM. THE PWR SHOWN HERE IS A TYPE OF REACTOR FUELED BY SLIGHTLY ENRICHED URANIUM IN THE FORM OF URANIUM OXIDE PELLETS HELD IN ZIRCONIUM ALLOY TUBES IN THE CORE. WATER IS PUMPED THROUGH THE CORE TO TRANSFER HEAT TO THE STEAM GENERATOR. THIS COOLANT WATER IS KEPT UNDER PRESSURE IN THE CORE TO PREVENT BOILING AND TRANSFERS HEAT TO THE WATER IN THE STEAM GENERATOR TO MAKE THE STEAM.

FIGURE 4.1-1. Pressurized Water Reactor

radioactive waste system, 5) the auxiliary building, which contains the liquid radioactive waste treatment systems, the filter and ion exchanger vaults, the gaseous radioactive waste treatment system, and the ventilation systems for the containment, fuel, and auxiliary buildings, 6) the control building, which houses the reactor control room and personnel facilities, 7) water intake structures, 8) the administration building, and 9) perhaps other structures such as warehouses and nonradioactive shops.

In a PWR, the reactor core and its pressure vessel are highly radioactive. So are the steam generators and the piping between the reactor and steam generators. Because the turbines are not directly connected to the primary loop, they are usually not radioactive unless there has been tube leakage in the steam generators. The cooling towers and associated piping are normally not radioactive. Much equipment in the auxiliary building is radioactive, as is the spent fuel storage pool and its associated equipment.

The major radiation problems in decommissioning are associated with the reactor itself, the primary loop, the steam generators, the radioactive waste handling systems, and the concrete biological shield that surrounds the pressure vessel.

4.2 REACTOR DECOMMISSIONING EXPERIENCE

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled. This was a 58.2-MWt BWR that was dismantled between 1971 and 1974. Though this reactor was quite small compared to present day commercial power reactors, one lesson stands out: reactors can be decontaminated with reasonable occupational radiation exposure and with virtually no public radiation exposure. At Elk River the containment building was kept intact until the pressure vessel and the biological shield were removed. Only after all of the radioactive metal components and concrete areas were removed, was the concrete containment building demolished. Of particular interest is the development of a remotely operated plasma arc torch that was used for cutting 1-1/2-inch-thick stainless steel under water and 3-1/2-inch-thick carbon steel in air.(3) For large reactors, 1,000-MWe, the cutting of 2-3/4-inch-thick stainless steel under water and 9-inch-thick carbon steel in air will be required.(4)

Other power reactors, all of them relatively small, have been placed in safe storage or entombed (see Table 1.5-1). These methods of decommissioning require some sort of surveillance, as mentioned in Section 2.3, and also require retention of a possession-only license. In the case of the Elk River reactor, all licenses were terminated.

4.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

4.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as the 4 years estimated for decommissioning after the end of reactor operation.

DECON is advantageous because it allows termination of the NRC license shortly after cessation of facility operations and thus removes a radioactive site. DECON is advantageous if the site is required for other purposes, if the site is extremely valuable, or, if for some reason the site must be immediately released for unrestricted use. It is also advantageous in that the reactor operating staff is available to assist with decommissioning and that continued surveillance and maintenance is not required. A disadvantage is the higher occupational radiation dose which occurs during DECON compared to the other alternatives.

The PNL study shows that DECON would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost \$33.3 million in 1978 dollars, including \$850,000 million for deep geologic disposal of activated components (Table 4.3-1). For comparison purposes, the time to plan and build a large power reactor is presently at least 12 years and the cost is well over one billion dollars.

Three important radiation exposure pathways need to be considered in the evaluation of the radiation safety of normal reactor decommissioning operations: inhalation, ingestion, and external exposure to radioactive materials. For decommissioning workers external exposure to radioactive materials is the dominant exposure pathway during decommissioning since inhalation and ingestion can be minimized or eliminated as pathways by protective techniques, clothing and breathing apparatus. For the public during decommissioning, inhalation is the dominant pathway of radiation exposure, since exposure to radioactive surfaces and ingestion can be minimized or eliminated as radiation pathways to the public during decommissioning. During the transport of radioactive wastes, exposure to radioactive materials is the dominant mode of radiation exposure to the public and to transportation workers since inhalation and ingestion can be minimized or eliminated as radiation pathways to workers and the public by techniques similar to that used during decommissioning. PNL calculated radiation doses for only the dominant pathways, and assumed the radiation doses from other pathways to be essentially zero. A summary of these doses is presented in Table 4.3-2.

TABLE 4.3-1. Summary of Estimated Costs for Decommissioning the Reference PWR in $ Millions[a,b]

Decommissioning Element	DECON	SAFSTOR			ENTOMB[c]	
		10 Years	30 Years	100 Years	Internals Included	Internals Removed
DECON[d]	33.3	NA[e]	NA	NA	NA	NA
Entombment[c]	NA	NA	NA	NA	21.0	27.0
Safe Storage Preparation[d]	NA	9.5	9.5	9.5	NA	NA
Continuing Care	NA	0.6[d]	2.2[d]	7.8[d]	0.040/yr	0.040/yr
Deferred Decontamination[d]	NA	31.1	31.1	24.5	NA	NA
Total	33.3	41.2	42.8	41.8	21.0 + $40 k/yr	27.0 + $40 k/yr

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[a] Values include a 25% contingency and are in constant 1978 dollars.

[b] Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and include cost of deep geologic disposal of dismantled, highly activated components.

[c] Reference 2, Table 4.5-1.

[d] Reference 1, Table 2.9-3 and Table H.5-2.

[e] NA-not applicable

TABLE 4.3-2. Summary of Estimated Costs for Decommissioning the Reference PWR in $ Millions[a,b]

	DECON	SAFSTOR			ENTOMB	
		10 Years	30 Years	100 Years	Internals Included	Internals Removed
Occupational Exposure						
Safe Storage Preparation[a]	NA[h]	279	279	279	NA	NA
Continuing Care[b]	NA	10	14	14	neg.	neg.
Decontamination[c,d]	1 083	329	24	1	NA	NA
Entombment[e]	NA	NA	NA	NA	900	1,000
Safe Stor. Prep. Truck Shipments[f]	NA	10.2	10.2	10.2	NA	NA
Decontamination Truck Shipments[f]	99.5	23.9	1.7	neg.	NA	NA
Entombment Truck Shipments[e]	NA	NA	NA	NA	20	25
Total	1 183	652	329	304	920	1,025
Public Exposure						
Safe Storage Preparation[g]	NA	neg.	neg.	neg.	NA	NA
Continuing Care[g]	NA	neg.	neg.	neg.	neg.	neg.
Decontamination[g]	neg.	neg.	neg.	neg.	NA	NA
Entombment[e]	NA	NA	NA	NA	neg.	neg.
Safe Stor. Prep. Truck Shipments[f]	NA	2.1	2.1	2.1	NA	NA
Decontamination Truck Shipments[f]	20.5	4.9	0.4	neg.	NA	NA
Entombment Truck Shipments[e]	NA	NA	NA	NA	3	4
Total	21	7	3	2	3	4

All references except (e) are from Reference 1. Values exclude radiation dose from disposal of last core.
(a)Table 11.3-2.
(b)Table 11.3-4.
(c)Table 11.3-1.
(d)Table H.6-1.
(e)Table 4.6-1 from Reference 2, with allowances for radioactive decay.
(f)Table 11.4-2, with allowances for radioactive decay.
(g)Table 11.2-2.
(h)NA-not applicable

The occupational radiation dose from external exposure to surface contamination and activated material, not including transportation of radioactive waste, is estimated to be about 1083 man-rem over 4 years (Table 4.3-2) or an average of 270 man-rem per year. The occupational radiation dose from the transportation of radioactive wastes is estimated to be about 99.5 man-rem to truck transportation workers from DECON waste shipments. For comparison purposes, the average annual occupational radiation dose from operation, maintenance, and refueling of PWRs from 1969 through 1975 was 430 man-rem per reactor.(5) In 1976 it was 450 man-rem.(6) This increase is considered to be due to build-up of radioactive contaminants with increasing reactor age,(7) and to increasing reactor size.(8)

The inhalation radiation dose to the public from airborne radionuclide releases during DECON is estimated to be negligible. The radiation dose to the public is calculated to be about 20.5 man-rem from the truck transportation of radioactive wastes from DECON.

4.3.2 SAFSTOR

Generally, the purpose of SAFSTOR is to permit ^{60}Co to decay to levels that will reduce occupational radiation exposure during decontamination. As indicated in Table 4.3-2, most of the occupational dose reduction due to decay occurs during the first 30 years after shutdown with considerably less dose reduction thereafter. The public dose, which is small to begin with, also experiences most of its reduction during the first 30 years. Nonradioactive equipment and structures need not be removed, but eventually all radioactivity in excess of that allowed for unrestricted use of the facility must be removed. Hence, in contrast to DECON, to take advantage of the dose reduction, SAFSTOR could be as long as 30 to 100 years before final decontamination. The end result is the same: release of the site and any remaining structures for unrestricted use.

SAFSTOR is advantageous in that it results in reduced occupational radiation exposure and, also, in situations where overriding land use considerations do not exist. Disadvantages are that the licensee is required to maintain a possession-only license under 10 CFR Part 50 and to meet its requirements at all times, thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantages are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the decontamination.

The PNL study, corresponding most closely to passive SAFSTOR, shows that the costs of SAFSTOR are greater than those of DECON and vary with the number of years of safe storage. For example, the total cost of 30-year SAFSTOR is estimated to be $42.8 million in 1978 dollars, and the total cost of 100-year SAFSTOR is estimated to be $41.8 million in 1978 dollars (the total cost of DECON is estimated to be $33.3 million in 1978 dollars). PNL's cost estimates are presented in Table 4.3-1.

SAFSTOR results in lower radiation doses to both the work force and to the public than DECON. The PNL study (Table 4.3-2) shows the occupational radiation dose to be approximately 317 man-rem for a 30-year SAFSTOR (279 man-rem from safe storage preparation, 14 man-rem for continuing care and surveillance, and 24 man-rem from deferred decontamination), not including transportation. The occupational radiation dose from the truck transportation of radioactive wastes is calculated to be about 12 man-rem. 100-year SAFSTOR results in little additional reduction in occupational radiation dose compared to 30-year SAFSTOR.

Radiation doses to the public from airborne radionuclide releases during preparation for safe storage are estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes during preparation for safe storage is estimated to be about 2.1 man-rem, and that from the truck transportation of radioactive wastes during deferred decontamination after 30 years of safe storage is estimated to be about 0.4 man-rem.

4.3.3 ENTOMB

ENTOMB means the complete isolation of radioactivity from the environment by means of massive concrete and metal barriers until the radioactivity has decayed to levels which permit unrestricted release of the facility. These barriers must prevent the escape of radioactivity and prevent deliberate or inadvertent intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radioactive nuclides present. A PWR that has been operated only a short time will contain ^{60}Co as the largest contributor to radiation dose. In this case, the integrity of the entombing structure need only be maintained for a few hundred years, as the disappearance of radioactivity is controlled by the 5.27-year half-life of ^{60}Co. If, on the other hand, the reactor has been operated for 30 or 40 years, substantial amounts of ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives) will have been accumulated as activation products in the reactor vessel internals. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 2 rem/hour (about 17,000 rem/year) while the dose from the ^{59}Ni in the internals is 0.1 rem/hour (about 880 rem/year). These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lifes of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. In addition, there are approximately 1,300 curies of ^{59}Ni in the reactor vessel internals which could result in potential internal exposures in the event of a breach of the entombed structure and subsequent introduction of the ^{59}Ni in an exposure pathway during the long half-life of ^{59}Ni. Thus, the long-lived isotopes will have to be removed or the integrity of the entombing structure will have to be maintained for many thousands of years.

ENTOMB of a PWR is limited to the containment building because its unique structure lends itself to entombment and because it contains most of the radioactivity in the facility. The other radioactive buildings associated with a reactor must be decommissioned by another method such as DECON. It is possible, however, to move some radioactive components from the fuel building or auxiliary building to the containment building and entomb them there, rather than ship them offsite.

ENTOMB is advantageous because of reduced occupational and public exposure to radiation compared to DECON, because little surveillance is required, and because little land is required. It is disadvantageous because the integrity of the entombing structure must be assured in some cases for hundreds of thousands of years, because a possession-only license under 10 CFR Part 50 would be required, and because entombing contributes to the number of sites permanently dedicated to radioactive containment.

PNL considered two approaches to entombment in an addendum(2) to its earlier PWR study.(1) In both approaches, as much solid radioactive material from the entire facility as can be accommodated is sealed in the containment building beneath the operating floor by means of a continuous concrete slab. All openings to the exterior beneath the operating floor are sealed. Above the operating floor, all radioactive material is reduced to levels which permit release of the facility for unrestricted use.

In the first approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are entombed, along with other radioactive material. This results in less cost and radiation exposure because the pressure vessel and its internals will not have to be removed, dismantled, and transported to a deep geologic waste repository. It will also, however, result in the requirement for a possession-only license and surveillance in perpetuity because of the presence of the long-lived isotopes.

In the second approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are removed, dismantled, and transported to a radioactive waste repository (a careful inventory of radioactivity would need to be made to ensure that only relatively short-lived isotopes remained). This results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility for unrestricted use.

Radioactive materials not entombed would have to be packaged and transported to a disposal site. Costs and radiation doses for this portion of the entombment procedure would be the same as for DECON. Cost savings and radiation dose reductions result from a lesser volume of radioactive equipment and material having to be dismantled, packaged, and transported. In any case, spent fuel would be removed.

ENTOMB for the reference PWR, including the pressure vessel and its internals, is estimated to cost $21 million, with an annual maintenance cost of $40,000. It results in a radiation dose of 900 man-rem to decommissioning workers, 20 man-rem to transportation workers, and 3 man-rem to the general public. ENTOMB for the reference PWR, with the pressure vessel internals removed, is estimated to cost $27 million, with an annual maintenance cost of $40,000, and to result in a radiation dose of 1,000 man-rem to decommissioning workers, 25 man-rem to transportation workers, and 4 man-rem to the general public. These estimates are listed in Tables 4.3-1 and 4.3-2.

4.3.4 Sensitivity Analyses

An addendum to the PNL study was developed(2) to analyze a variety of realistic decommissioning situations that might significantly impact on the original conclusions regarding doses and costs for the various decommissioning alternatives. While there were some differences in results, the conclusion of the sensitivity analysis is that these differences do not substantially effect the original cost and dose conclusions. Of the various situations analyzed by PNL in the addendum, the most important with regard to their potential effect on dose and cost estimates are reactor size and degree of contamination.

In analyzing the sensitivity of decommissioning costs and radiation doses to reactor size, PNL examined three PWRs in addition to the reference reactor in order to develop algebraic expressions for decommissioning costs and doses that would span the range of sizes of presently operating PWRs. The four plants examined were Yankee-Rowe (600 MWt), R. E. Ginna (1,300 MWt), Turkey Point (2,550 MWt) and the reference plant, Trojan (3,500 MWt). An overall scaling factor (OSF) was obtained:

$$\mathrm{OSF} = 0.2352 + 2.173 \times 10^{-4}\ (\mathrm{MWt}),$$

which can be used to determine costs and radiation doses for decommissioning plants of sizes between 600 MWt and 3,500 MWt for any decommissioning alternative discussed in this section. Table 4.3-3 presents a list of variations in dose and cost for several PWRs based on this formula. The cost of demolition of nonradioactive structures is stated separately.

The addendum also analyzed the sensitivity of decommissioning costs and radiation doses related to a postulated tripling of radiation dose rates from radionuclides deposited in PWR coolant system piping during reactor operation over a period of 30 to 40 years. This tripling of dose rate is postulated as an upper limit on the basis of recent trends for operating reactors. If no corrective action is taken to reduce the radiation dose rates, the accumulated radiation dose to decommissioning workers for DECON would be increased about 1,250 man-rem[a], and the decommissioning costs could be increased by about $2.6 million for DECON. For ENTOMB the radiation dose would be nearly doubled and the cost could be increased about $1.8 million. For preparations for safe storage, the radiation dose would be increased about 130 man-rem, and there would be no significant change

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[a] This number excludes removal of last core and allows for radioactive decay.

TABLE 4.3-3. Estimated Costs and Occupational Radiation Doses for Decommissioning Different-Sized PWR Plants[a]

		Station			
		Yankee-Rowe	R. E. Ginna	Turkey Point	Trojan
Power Rating	(thermal megawatts)	600	1 300	2 550	3 500
Overall Scaling Factor	(OSF[MWt])	0.366	0.518	0.789	1.000
DECON	($millions)	11.3	16.1	24.5	31.0
	(man-rem)	513	727	1 108	1 404
ENTOMB[c]					
w/internals	($ millions)[c]	7.7	10.9	16.6	21.0
	(man-rem)	329	466	710	900
w/o internals	($ millions)	9.1	12.8	19.5	24.7
	(man-rem)	366	518	789	1 000
SAFSTOR					
Preparations for Safe Storage	($ millions)	3.4	4.9	7.4	9.5
	(man-rem)	156	221	336	426
Safe Storage: for 30 years	($ millions)	2.4	2.4	2.4	2.4
	(man-rem)	14	14	14	14
for 50 years	($ millions)	4.0	4.0	4.0	4.0
	(man-rem)	14	14	14	14
for 100 years	($ millions)	7.9	7.9	7.9	7.9
	(man-rem)	14	14	14	14
Deferred Dismantlement:					
after 30 years	($ million)	10.5	14.9	22.8	28.9
	(man-rem)	11	16	24	30
after 50 years	($ million)	8.2	11.6	17.6	22.3
	(man-rem)	0.9	1.2	1.9	2.4
after 100 years	($ millions)	8.2	11.6	17.6	22.3
	(man-rem)	0.4	0.6	1.0	1.2
Facility Demolition	($ millions)	2.5	4.1	6.5	8.0

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[a] Costs do not include spent-fuel disposal.

[b] Doses are taken from Ref. 2 and do not include transportation doses and do not take credit for radioactive decay during decommissioning.

[c] Entombment costs do not include continuing care costs ($0.04 M/yr).

in the cost. If corrective action is taken, such as an extended chemical decontamination cycle, the total additional cost could be about $85,000.

In order to handle these higher initial radiation levels postulated, it appears that additional chemical decontamination during decommissioning would be the most cost-effective approach. For example, it is estimated that increasing the circulation time of the chemical solution about 50% would reduce the postulated increased radiation levels by a factor of 3, thus reducing these levels to approximately the same dose rate conditions assumed in the reference case analysis. This approach would also be more consistent with the principles of ALARA, since the occupational radiation dose associated with a chemical decontamination cycle is relatively small, compared with the radiation dose associated with installing temporary shielding, or with attempting to perform the dismantlement without additional shielding. In addition, it appears likely that the large buildups of radionuclides prevalent today on piping systems will be prevented as periodic decontamination during normal operation of the reactor coolant system and related fluid-handling systems becomes standard procedure when the present technology development for decontamination solutions has been completed.

There are many areas where various planned design and operational features could facilitate decommissioning. Exploration of such areas was considered by PNL(1) in their initial decommissioning study. It was concluded that appropriate measures could not only significantly reduce decommissioning occupational dose and radioactively contaminated waste volume but also reduce occupational dose during reactor operation. Preliminary considerations of various design and operational features that could further facilitate decommissioning and their impacts on doses and costs appears in a recently published PNL study.(9)

4.4 ENVIRONMENTAL CONSEQUENCES

Radiation doses and costs associated with possible decommissioning alternatives are discussed in Section 4.3. It is noted for perspective that in the cases of DECON and SAFSTOR, the environmental effects of greatest concern, (i.e., radiation dose and radioactivity released to the environment) are substantially less than the same effects associated with reactor operation and maintenance. It should also be noted that while the dollar costs of ENTOMB are less than those of DECON, the environmental costs could be quite high should large amounts of radioactivity escape from a breached structure during the entombment period.

Other environmental consequences are rather different from the environmental consequences usually discussed in environmental impact statements. This is because, usually, an environmental impact statement is addressed to the consequences of building a facility that will require land, labor, capital investment, materials, continuing use of air, water, and fuel; a socio-economic infrastructure; and so on. Decommissioning, on the other hand, is an attempt to restore things to their original condition, which requires a much smaller commitment of resources than did building and operating the facility.

A major environmental consequence of decommissioning, other than radiation dose and dollar cost, is the commitment of land area to the disposal of radioactive waste. PNL made the estimates shown in Table 4.4-1 of the low-level waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. Reduction in waste volume for SAFSTOR occurs as many of the contamination and activation products present in the facility will have decayed to background levels. The volume for ENTOMB does not include the volume of the entombing structure or of the wastes entombed within it. The entombing structure is in effect a new radioactive waste burial ground, separate and distinct from the ones in which the wastes in Table 4.4-1 are buried.

TABLE 4.4-1. Burial Volume of Low-Level Radioactive Waste and Rubble for the Reference PWR

Decommissioning Alternative		Volume (m^3)
DECON		17 900
SAFSTOR		
Deferred Decontamination[b] following Safe Storage for:	10 Years	17 900
	30 Years	17 900[c]
	50 Years	1 830
	100 Years	1 780
ENTOMB[a]		1 740

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[a] Does not include the volume of the entombing structure or of the wastes within.

[b] Radioactive wastes from preparation for safe storage and during safe storage are small in comparison to those of deferred decontamination.

[c] Although, in actuality, there is a more gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

If shallow-land burial of radioactive wastes in standard trenches is assumed, then a burial volume of 17,900 m^3 of radioactive waste can be accommodated in less than 2 acres. The two acres is not large in comparison with the 1,160 acres used as the site of the reference PWR.

It is likely that certain highly activated components of the reactor and its internals will be placed in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very long half-lives of ^{59}Ni and ^{94}Nb. Only approximately 11 m^3 of material would be involved, but deep geologic disposal would add approximately $850,000 to the cost of decommissioning and would require approximately 88 m^3 of waste disposal space. This cost has been included in the costs of decommissioning shown in Table 4.3-1.

PNL considered accidental releases of radioactivity both during decommissioning and during transport of wastes. Radiation doses to the maximum-exposed individual from accidental airborne radioactivity releases during decommissioning operations were calculated to be quite low (Table 4.4-2). Radiation doses to the maximum-exposed individual from accidental radioactivity releases resulting from truck accidents were calculated to be moderate for the most severe accident (Table 4.4-3).

Other environmental consequences of decommissioning are minor compared to the environmental consequences of building and operating a PWR. Water use and evaporation at the rate of as much as 27×10^6 m^3/yr ceased when the reactor ceased operation. Total water use for decommissioning should not exceed 18×10^3 m^3. The number of workers on site at any time will not be much greater than when the PWR was in operation and will be much less than when the PWR was under construction. The transportation network is already in place, but will require some maintenance if the SAFSTOR alternative is selected.

Disturbance of the ground cover need not take place to any appreciable extent except for filling holes and leveling the ground following removal of underground structures, unless extended operation of the plant has resulted in contamination of the ground around the plant. Plowing of the ground would generally result in lowering contamination levels to that acceptable for releasing the site for unrestricted use, except for a few more

TABLE 4.4-2. Summary of Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During Decommissioning Operations

Incident	Immediate Dismantlement					Preparations for Safe Storage					Estimated Frequency of Occurrence[b]
	Airborne Release (μCi)	First-Year Dose (mrem)		Fifty-Year Dose Commitment (mrem)		Airborne Release (μCi)	First-Year Dose (mrem)		Fifty-Year Dose Commitment (mrem)		
		Total Body[a]	Lung	Total Body	Lung		Total Body[a]	Lung	Total Body	Lung	
Explosion of LPG Leased from a Front End Loader	3.6×10^{3}	3.6×10^{-2}	4.7×10^{-2}	4.4×10^{-2}	5.4×10^{-2}	---[c]					Low
Explosion of Oxyacetylene During Segmenting of the Reactor Vessel Shell	3.5×10^{2}	4.3×10^{-3}	6.1×10^{-3}	6.9×10^{-3}	6.9×10^{-3}	---					Medium
Explosion and/or Fire in the Ion Exchange Resin	3.8×10^{1}	3.8×10^{-4}	5.0×10^{-4}	4.6×10^{-4}	5.7×10^{-4}	---					Medium
Gross Leak During In Situ Decontamination	2.1×10^{1}	2.1×10^{-4}	2.8×10^{-4}	2.5×10^{-4}	3.2×10^{-4}	2.1×10^{1}	2.1×10^{-4}	2.8×10^{-4}	2.5×10^{-4}	3.2×10^{-4}	Medium
Segmentation of RCS Piping with Unremoved Contamination	1.1×10^{1}	4.6×10^{-6}	7.3×10^{-4}	4.8×10^{-6}	7.9×10^{-4}	---					High
Loss of Contamination Control Envelope During Oxyacetylene Cutting of the Reactor Vessel Shell	2.3×10^{2}	---	---	---	4.4×10^{-4}	---					Medium
Vacuum Bag Rupture	---					1.0×10^{2}	1.1×10^{-3}	1.3×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	Medium
Accidental Cutting of Contaminated Piping	---					1.8×10^{-1}	---	1.2×10^{-5}	---	1.3×10^{-5}	High
Accidental Spraying of Concentrated Contamination with the High Pressure Spray	---					1.2×10^{-1}	---	1.6×10^{-5}	1.5×10^{-6}	1.8×10^{-6}	High

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(a) The average annual total body dose to an individual in the U.S. from natural sources ranges from 80 to 170 mrem. United Nations Scientific Committee on th Effects of Atomic Radiation, Ionizing Radiation: Levels and Effects. Volume I, United Nations, pp. 29-63, 1972.

(b) Frequency of occurrence: high $>1.0 \times 10^{-2}$, medium 1.0×10^{-2} to 1.0×10^{-5}; low $< 1.0 \times 10^{-5}$ per year.

(c) A dash indicates a dose less than 1.0×10^{-6} mrem or that this action does not apply to the decommissioning mode shown.

TABLE 4.4-3. Estimated Frequencies and Radioactivity Releases for Selected Truck Transport Accidents

Accident Description	Frequency of Accidents per DECON	Frequency of Accidents Per SAFSTOR	Release, Curies	Radiation Dose for Maximum Individual, (rem)(a)			
				1st Year Dose		50 Yr Dose Commitment	
				Bone	Lung	Bone	Lung
Truck Transport of Decommissioning Wastes(b,c)							
Minor Accident with Closed Van	8.8×10^{-1}	9.0×10^{-2}	No Release	--	--	--	--
Moderate Accident with Closed Van	2.1×10^{-1}	2.1×10^{-2}	1×10^{-4}	0.01	0.2	0.01	0.2
Severe Accident with Closed Van	5.6×10^{-3}	5.7×10^{-4}	1×10^{-2}	1.1	21	1.1	24

(a) Maximum-exposed individual is assumed at 100 m from the site of the accident.

(b) Based on an inventory of 100 Ci per truck shipment.

(c) Release fractions for respirable material for moderate and severe accidents are assumed to be 10^{-6} and 10^{-4} respectively.

highly contaminated areas which would have to be removed. In this case, soil to a depth of several centimeters and some paving may have to be removed, packaged, and shipped to a disposal facility before the site can be released for unrestricted use.

The biggest socio-economic impact will have occurred before decommissioning started, at the time the plant ceased operation and the tax income created by the plant disappeared. No additional public services will be required because the decommissioning staff will be approximately the same size as the operating staff; although in the case of deferred decontamination, the decontamination staff will be larger than the surveillance staff.

4.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

From careful examination of Tables 4.3-1 and 4.3-2 it appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a PWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger occupational radiation dose is considered of marginal significance to health and safety, and, therefore, DECON would be considered the more preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR.

Either ENTOMB option requires indefinite dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay, so this option is not viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory uncertainty after the long entombment time period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

It is instructive to consider the cumulative impact of decommissioning all existing and planned PWRs. In 1977 there were 36 PWRs in operation, with a total electric-power-producing capacity of 27,000 MWe. The environmental impact of decommissioning these 36 reactors will be approximately 3[illegible] times the impact of decommissioning the 1,175-MWe reference reactor discussed here. This impact will increase as the number of PWRs increases, although one might expect some mitigation of the impact of decommissioning, based on decommissioning experience or if future reactors are sited near waste disposal facilities or in multiple reactor sites (see Section 13).

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service.

5.0 BOILING WATER REACTOR

A boiling water reactor (BWR), like a pressurized water reactor (PWR), is a facility for converting the thermal energy of a nuclear reaction into the kinetic energy of steam to drive a turbine-generator and produce electricity. In a BWR, the conversion is accomplished by heating water to boiling in the reactor pressure vessel and using the resulting steam to drive the turbines. The intermediate step, present in a PWR, of converting pressurized hot water into steam through a heat exchanger in a steam generator is not used in a BWR. Elimination of this step also eliminates one cooling loop.

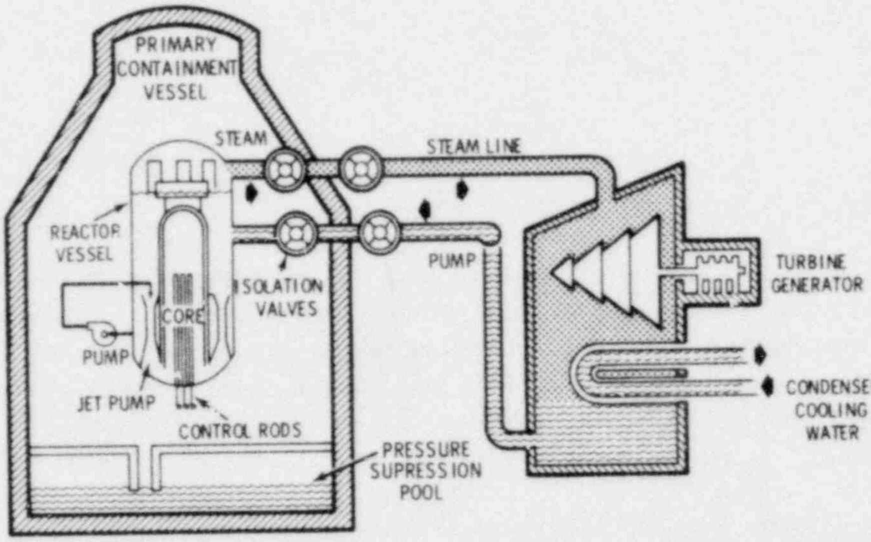
The generic site for the reference 1155-MWe BWR is assumed to be typical of reactor locations and is described in Section 3.1. As in the case of a PWR, the specific site for a BWR is chosen on the basis of operational and regulatory criteria, usually with little regard for decommissioning. Fortunately, factors that are appropriate for siting, such as transportation access, water supply, and skilled labor supply, are also appropriate for decommissioning. Thus, the decommissioning alternative chosen will not usually depend on siting considerations, but rather on safety, costs, and land use options at the time of decommissioning. These considerations are discussed in Section 4 for a PWR, and apply equally to a BWR.

In this section, we have used information prepared for the study on the technology, safety and costs of decommissioning a reference BWR, which was conducted by Pacific Northwest Laboratory (PNL) for the NRC.(1) In the BWR study, PNL selected the Washington Public Power Supply System's WNP-2 1155-MWe reactor at Hanford, Washington, as the reference BWR and assumed it to be located on the generic site. PNL then developed and reported information on the available technology, safety consideration, and probable costs for decommissioning the reference facility at the end of its operating life. In addition, as part of this study, PNL did a sensitivity study to analyze the effect that variation of certain parameters might have on doses and costs of decommissioning. The parameters which were varied included reactor size, degree of radioactive contamination, type of containment structure, etc.

5.1 BOILING WATER REACTOR DESCRIPTION

The major components of a BWR are a reactor core and pressure vessel, steam turbines, an electric generator, and a steam condenser system (Figure 5.1-1). Water is boiled in the reactor pressure vessel to create steam at high temperature and pressure, which then passes through the primary circulation loop to drive the turbines. The turbines turn the generator, which produces electricity. The steam leaving the turbines is condensed by water in the secondary loop and flows back to the reactor. The water in the secndary loop flows to the cooling towers where it is in turn cooled by evaporation. The secondary cooling loop is open to the atmosphere, but the primary loop is not.

Buildings or structures associated with the reference BWR include 1) the reactor building which houses the reactor pressure vessel, the containment structure, the biological shield, new and spent fuel pools, and fuel handling equipment; 2) the turbine generator building which houses the turbines and electric generator; 3) the radwaste and control building which houses the solid, liquid, and gaseous radioactive waste treatment systems, and the main control room; 4) the cooling towers; 5) the diesel generator building which houses auxiliary diesel generators; 6) water intake structures and pump houses; 7) the service building which houses the makeup water treatment system, machine shops, and offices; and 8) other minor structures.



A NUCLEAR POWER REACTOR PRODUCES STEAM TO DRIVE A TURBINE WHICH TURNS AN ELECTRIC GENERATOR. THE BWR SHOWN HERE IS A TYPE OF REACTOR FUELED BY SLIGHTLY ENRICHED URANIUM IN THE FORM OF URANIUM OXIDE PELLETS HELD IN ZIRCONIUM ALLOY TUBES IN THE CORE. WATER IS PUMPED THROUGH THE CORE, BOILS, AND PRODUCES STEAM THAT IS PIPED TO THE TURBINE.

FIGURE 5.1-1. Boiling Water Reactor

In the reference BWR, the reactor building, the turbine generator building, and the radwaste building are the only buildings containing radioactive materials. The reactor core and its pressure vessel are highly radioactive, as is the piping to the turbines. The turbines are also radioactive, but the cooling towers and associated piping are not, since the design of the system is such that any leakage would be from the nonradioactive secondary loop to the primary loop. Much equipment in the radwaste building is radioactive, as is the spent fuel pool in the reactor building.

The major sources of radiation in decommissioning a BWR are associated with the reactor itself, the containment structure, the concrete biological shield, the primary loop, the turbines, and the radwaste handling systems.

5.2 BWR DECOMMISSIONING EXPERIENCE

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled.(2) This was a 58.2-MWt BWR that was dismantled between 1971 and 1974. While this reactor was quite small compared to present-day power reactors, its decommissioning served to demonstrate that reactors can be decontaminated safely with little occupational or public risk. At Elk River, the containment building was kept intact until the pressure vessel and biological shield were removed. Only after all of the radioactive metal components and concrete areas were removed was the concrete containment structure demolished.

Other reactors, all of them relatively small, have been placed in safe storage or entombed (Table 1.51). Safe storage and entombment require surveillance and retention of a possession-only license. At Elk River, all licenses were terminated.

5.3 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

5.3.1 DECON

DECON means the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as 4 years after the end of reactor operation.

DECON is advantageous because it allows termination of the NRC license shortly after cessation of facility operations and thus removes a radioactive site. DECON is advantageous if the site is required for other purposes, if the site has become extremely valuable, or if the site for some reason must be immediately released for unrestricted use. It is also advantageous in that the reactor operating staff is available to assist with decommissioning and that continued surveillance and maintenance is not required. A disadvantage is the higher occupational radiation dose which occurs during DECON compared to the other alternatives.

The PNL study shows that DECON would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost $43.6 million in 1978 dollars (Table 5.3-1). In comparison, the time to plan and build a large power reactor in the United States is presently at least 12 years and the cost is well over one billion dollars.

Three important radiation exposure pathways need to be considered in the evaluation of the radiation safety of normal reactor decommissioning operations: inhalation, ingestion, and external exposure to radioactive materials. For reasons similar to that discussed for PWRs in section 4.3.1, during decommissioning the dominant exposure pathway to workers is external exposure while for the public the dominant exposure pathway is inhalation. During the transport of radioactive waste, the dominant exposure pathway is external exposure for both transportation workers and the public. A summary of the doses resulting from these pathways is presented in Table 5.3-2.

The occupational radiation dose from external exposure to surface contamination and activated material, not including transportation of radioactive waste, is estimated to be about 1845 man-rem, or an average of 460 man-rem per year. (Table 5.3-2). The occupational radiation dose to truck transportation workers from DECON waste shipments is estimated to be about 110 man-rem. In comparison, the annual occupational radiation dose from operation, maintenance, and refueling of BWRs from 1969 through 1975 was approximately 340 man-rem per reactor.(3)

The inhalation radiation dose to the public from airborne radionuclide releases during DECON is estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes from DECON is estimated to be about 10 man-rem.

A major reason for the difference in cost and radiation dose between DECON of a BWR and a PWR is the requirement to dismantle, remove, and dispose of the radioactive turbine, condenser, and main steam piping of a BWR. A PWR turbine is not significantly contaminated with radioactivity since the major portion of the radioactivity is confined to the primary coolant systems.

5.3.2 SAFSTOR

Generally, the purpose of SAFSTOR is to permit residual radioactivity to decay to levels that will reduce occupational radiation exposure during decontamination. As indicated in Table 5.3-2, most of the occupational dose reduction due to decay occurs during the first 30 years after shutdown with considerably less dose reduction thereafter. The public dose which is small to begin with, also experiences most of its reduction during the first 30 years. Nonradioactive equipment and structures need not be removed, but eventually all radioactivity in excess of that allowed for unrestricted use of the facility must be removed. Hence, in contrast to DECON, to take advantage of the dose reduction, the safe storage period could be as long as 30 to 100 years before final decontamination. The end result is the same: release of the site and any remaining structures for unrestricted use.

SAFSTOR is advantageous in that it results in reduced occupational radiation exposure and in situations where overriding land use considerations do not exist. Disadvantages are that the owner is required to maintain a possession-only license under 10 CFR Part 50 during the safe storage phase and to meet its requirements at all times thus contributing to the number of sites dedicated to radioactive containment for an extended time period. Other disadvantages are that surveillance and monitoring are required, the cumulative dollar costs are higher than for DECON and the operating staff will not be available at the end of the safe storage period to assist in the decontamination.

The PNL study, corresponding most closely to passive storage, shows that the costs of SAFSTOR are greater than those of DECON and vary with the number of years of safe storage. For example, the total cost of 30-year SAFSTOR is estimated to be \$58.9 million in 1978 dollars, and the total cost of 100-year SAFSTOR is estimated to be \$55 million in 1978 dollars (compared with the total cost of \$44.7 million for DECON). The lower cost for 100-year SAFSTOR compared to 30-year is the result of lower costs for deferred decontamination due to the radioactivity having decayed to lower levels. Table 5.3-1 presents PNL's estimated costs for the decommissioning alternatives.

SAFSTOR results in lower radiation doses to both the work force and the public than DECON or ENTOMB. The occupational radiation dose is estimated to be approximately 418 man-rem for 30-year SAFSTOR (375 man-rem from safe storage preparation, 7 man-rem from continuing care, and 36 man-rem from deferred decontamination), not including transportation (Table 5.3-2). The occupational radiation dose from the truck transportation of radioactive wastes is estimated to be about 24 man-rem. For 100-year SAFSTOR the estimated occupational radiation dose is estimated to be approximately 407 man-rem (375 man-rem from safe storage preparation, 10 man-rem from continuing care, and a negligible dose from deferred decontamination). The occupational radiation dose from the truck transportation of radioactive wastes is estimated to be about 22 man-rem. Thus, 100-year SAFSTOR results in little additional reduction in occupational radiation dose compared to 30-year SAFSTOR.

Radiation doses to the public from airborne radionuclide releases resulting from SAFSTOR are estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes during the preparation for safe storage is estimated to be about 2 man-rem, and that from the truck transportation of radioactive wastes during deferred decontamination after 30 and 100 years of safe storage is estimated to be negligible.

5.3.3 ENTOMB

ENTOMB means the complete isolation of radioactivity from the environment by means of massive concrete and metal barriers until the radioactivity has decayed to levels which permit unrestricted release of the facility. These barriers must prevent the escape of radioactivity and prevent deliberate or inadvertent intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radioactive nuclides present. A BWR will contain ^{60}Co as the largest contributor to radiation dose. If it has been operated only a short time the integrity of the entombing structure need only be maintained for a few hundred years, as the disappearance of radioactivity is controlled by the 5.27-year half-life of ^{60}Co. If, on the other hand, the reactor has been operated for 30 or 40 years, substantial amounts of ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives) will have been accumulated as activation products in the reactor vessel internals. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 0.7 rem/hour (about 6100 rem/year) while the dose from the ^{59}Ni in the internals is 0.07 rem/hour (about 600 rem/year). These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lives of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. In addition, there are on the order of 1,000 curies of ^{59}Ni in the reactor vessel internals which could result in potential internal exposures in the event of a breach of the entombed structure and subsequent introduction of the ^{59}Ni in an exposure pathway during the long half-life of ^{59}Ni. Thus, the long-lived isotopes will have to be removed or the integrity of the entombing structure will have to be maintained for many thousands of years.

ENTOMB for a BWR is limited to the containment vessel because its unique structure lends itself to entombment and because it contains most of the radioactivity in the facility. Other buildings associated with a reactor must be decommissioned by another method such as DECON. It is possible, however, to move some radioactive components from other buildings to the containment vessel and ENTOMB them there, rather than shipping them offsite.

ENTOMB is advantageous because of reduced occupational and public exposure to radiation compared to DECON, because little surveillance is required, and because little land is required. It is disadvantageous because the integrity of the entombing structure must be assured in some cases for hundreds of thousands of years, because a possession-only license under 10 CFR Part 50 would be required which in turn requires some surveillance, monitoring, and maintenance, and because entombing contributes to the number of sites dedicated to radioactive containment for very long time periods.

Two approaches to the ENTOMB alternative for a BWR are possible. In both approaches, as much solid radioactive material from the entire facility as can be accommodated is sealed within the containment vessel. All openings to the exterior are sealed. Radioactive material outside the containment vessel is removed down to levels which permit release of the facility for unrestricted use.

In the first approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are entombed, along with other radioactive material. This results in less cost and radiation dose because the pressure vessel and its internals will not have to be removed, dismantled, and transported to a deep geologic waste repository. It will also, however, result in the requirement for a possession-only license and indefinite surveillance because of the presence of the long-lived isotopes.

In the second approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are removed, dismantled, and transported to a radioactive waste repository. This results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility for unrestricted use. At the outset, a careful inventory of radioactivity would need to be made to ensure that only relatively short-lived isotopes were present.

Radioactive materials not entombed would have to be packaged and transported to a disposal site. Cost savings and radiation dose reductions would result from the lesser volume of radioactive equipment and material having to be dismantled, packaged, and transported. In any case, all spent fuel would be removed.

ENTOMB for the reference BWR, including the pressure vessel and its internals, is estimated to cost $35.0 million, with an annual surveillance and maintenance cost of $40,000. It results in a radiation dose of 1573 man-rem to decommissioning workers, 51 man-rem to transportation workers, and 5 man-rem to the general public. ENTOMB for the reference BWR, with the pressure vessel internals removed, is estimated to cost $40.6 million, with an annual surveillance and maintenance cost of $40,000, and to result in a radiation dose of 1684 man-rem to decommissioning workers, 69 man-rem to transportation workers, and 7 man-rem to the general public. These estimates are listed in Tables 5.3-1 and 5.3-2.

TABLE 5.3-1. Summary of Estimated Costs for Decommissioning the Reference BWR in $ Millions[a,b]

Decommissioning Element	DECON	SAFSTOR After 10 Years	SAFSTOR After 30 Years	SAFSTOR After 100 Years	ENTOMB with Internals Included	ENTOMB with Internals Removed
DECON	43.6	NA	NA	NA	NA	NA
Entombment	NA	NA	NA	NA	35.0	40.6
Safe Storage Preparation	NA	21.3	21.3	21.3	NA	NA
Continuing Care	NA	0.6	2.1	7.4	$40 k/yr	$40 k/yr
Deferred Decontamination	NA	35.5	35.5	26.4	NA	NA
Total	43.6	57.4	58.9	55.0	35.0 + $40 k/yr	40.6 + $40 k/yr

(a)All entries are from Reference 1. NA means not applicable.

(b)Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and include cost of deep geologic disposal of dismantled, highly activated components.

TABLE 5.3-2. Summary of Radiation Safety Analyses for Decommissioning the Reference BWR (values are in man-rem)[a]

	DECON	SAFSTOR After 10 Years	SAFSTOR After 30 Years	SAFSTOR After 100 Years	ENTOMB Internals Included	ENTOMB Internals Removed
Occupational Exposure						
Safe Storage Preparation	NA	375	375	375	NA	NA
Continuing Care	NA	1	7	10	neg.	neg.
Decontamination	1 845	495	36	neg	NA	NA
Entombment	NA	NA	NA	NA	1 573	1 684
Safe Stor. Prep. Truck Shipments	NA	22	22	22	NA	NA
Decontamination Truck Shipments	110	38	2	neg	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	51	69
Total	1 955	931	442	407	1 624	1 753
Public Exposure						
Safe Storage Preparation	NA	neg	neg	neg	NA	NA
Continuing Care	NA	neg	neg	neg	neg.	neg.
Decontamination	neg	neg	neg	neg	NA	NA
Entombment	NA	NA	NA	NA	neg	neg
Safe Stor. Prep. Truck Shipments	NA	2	2	2	NA	NA
Decontamination Truck Shipments	10	3	neg	neg	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	5	7
Total	10	5	2	2	5	7

(a)All entries are from Reference 1. Values exclude radiation dose from disposal of last core (101 man-rem). NA means not applicable and neg means negligible.

5.3.4 Sensitivity Analyses

In addition to the reference BWR, PNL also analyzed a variety of realistic decommissioning situations.(1) These variations were studied to determine if they might have significant impact on the conclusions reached for the reference BWR regarding doses and costs for the decommissioning alternatives. While there were some differences in results, the conclusion of the sensitivity analysis is that these differences do not substantially affect the original cost and radiation dose conclusions. Of the various situations analyzed by PNL, the most important with regard to their potential effect on dose and cost estimates are reactor size, degree of contamination and type of containment structure.

In analyzing of the sensitivity of decommissioning costs and radiation doses to reactor size, PNL examined six BWRs in addition to the reference reactor in order to develop algebraic expressions for decommissioning costs and doses that would span the range of sizes of presently operating BWRs. The seven plants examined were Vermont Yankee (1593 MWt), Oyster Creek (1600 MWt), Monticello (1670 MWt), Cooper (2381 MWt), Dresden 2 or 3 (2527 MWt), Peach Bottom 2 or 3 (3293 MWt), and the reference plant WNP-2 (3320 MWt). They obtained an overall scaling factor (OSF):

$$\text{OSF} = 0.324 + 2.035 \times 10^{-4}\ (\text{MWt}),$$

which can be used to determine costs and radiation doses for decommissioning plants of sizes between 1593 MWt and 3320 MWt for any decommissioning alternative discussed in this section. Table 5.3-3 presents a list of variations in dose and cost for several BWRs based on this formula. The cost of demolition of nonradioactive structures is stated separately.

Also analyzed was the sensitivity of decommissioning costs and radiation doses to a postulated tripling of radiation dose rates from radionuclides deposited in BWR coolant system piping during reactor operation over a period of 30 to 40 years. This tripling of dose rate is postulated as an upper limit on the basis of recent trends for operating reactors. If no corrective action is taken to reduce the radiation dose rates, the accumulated radiation dose to decommissioning workers for DECON would be increased from 1845 man-rem to 4573 man-rem,(1) and the decommissioning costs could be increased by about $6 million for DECON. For ENTOMB the radiation dose would be increased from 1684 man-rem to 4154 man-rem and the cost could be increased about $6 million. For preparation for safe storage, the radiation dose would be increased from 375 man-rem to 759 man-rem, and there would be no significant change in the cost.

In order to handle these higher initial radiation levels postulated, it appears that additional chemical decontamination during decommissioning would be the most cost-effective approach. For example, it is estimated that increasing the circulation time of the chemical solution about 50% would reduce the postulated increased radiation levels by a factor of 3, thus reducing these levels to approximately the same dose rate conditions assumed in the reference case analysis. This approach would also be more consistent with the principles of ALARA, since the occupational radiation dose associated with a chemical decontamination cycle is relatively small, compared with the radiation dose associated with installing temporary shielding, or with attempting to perform the dismantlement without additional shielding. In addition, it appears likely that the large buildups of radionuclides prevalent today on piping systems will be prevented as periodic decontamination during normal operation of the reactor coolant system and related fluid-handling systems becomes standard procedure when the present technology development for decontamination solutions has been completed.

Analysis was also done to determine if variation in design of the BWR containment structure would have significant impact on doses or costs of decommissioning. There are three principal designs of BWR containments and pressure suppression systems, namely Mark I, Mark II, and Mark III and these were analyzed by PNL. The conclusion

TABLE 5.3-3. Estimated Costs and Occupational Radiation Doses for Decommissioning Different-Sized BWR Plants[a][b]

		Station		
		Vermont Yankee	Cooper	WNP-2
Power Rating	(thermal megawatts)	1 593	2 381	3 320
Overall Scaling Factor	(OSF)	0.648	0.809	1.000
DECON	($millions)	28.3	35.3	43.6
	(man-rem)	1 196	1 493	1 845[b]
ENTOMB[c]				
w/internals	($ millions)[c]	22.7	28.3	35.0
	(man-rem)	1 019	1 273	1 573
w/o internals	($ millions)	26.3	32.8	40.6
	(man-rem)	1 091	1 362	1 684
SAFSTOR				
Preparations for Safe Storage	($ millions)	13.8	17.2	21.3
	(man-rem)	243	303	375
Safe Storage: for 30 years	($ millions)	2.0	2.0	2.1
	(man-rem)	6.5	6.5	6.5
for 50 years	($ millions)	3.4	3.4	3.4
	(man-rem)	10	10	10
for 100 years	($ millions)	6.9	6.9	7.4
	(man-rem)	10	10	10
Deferred Dismantlement:				
after 30 years	($ million)	23.0	27.8	35.5
	(man-rem)	23	29	36
after 50 years	($ million)	17.1	21.4	26.4
	(man-rem)	1.9	2.4	3
after 100 years	($ millions)	17.0	21.3	26.4
	(man-rem)	>1	>1	>1
Facility Demolition	($ millions)	13.7	15.0	16.6

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[a] Costs do not include spent-fuel disposal.

[b] Doses do not include those due to transportation of wastes.

[c] ENTOMB costs do not include continuing care costs ($0.04 M/yr).

reached by this analysis was that for BWR plants of equivalent power rating, differences in containment design have very little effect on the total cost of decommissioning of a BWR.

Other methods of facilitating decommissioning, in addition to additional chemical decontamination, are discussed in NUREG/CR-0569.(4) These include improved documentation, reduction of radwaste volume by incineration, electropolishing of piping and components as a decontamination technique, remote maintenance and decommissioning equipment (robots), improved access to piping and components, and improved concrete protection.

5.4 ENVIRONMENTAL CONSEQUENCES

Radiation doses and costs associated with possible decommissioning alternatives are discussed in Section 5.3. It is to be emphasized for perspective that for any viable decommissioning alternative, the environmental effects of greatest concern, i.e., radiation dose and radioactivity released to the environment, are substantially less than the same effects associated with operation and maintenance of the reactor over its useful lifetime. It should also be noted that while the dollar costs of ENTOMB are less than those of DECON, the environmental costs could be quite high should large amounts of radioactivity escape from a breached structure during the entombment period.

Other environmental consequences are rather different from the environmental consequences usually discussed in environmental impact statements. This is because, usually, an environmental impact statement is addressed to the consequences of building a facility that will require land, labor, capital investment, materials, continuing use of air, water and fuel, a socio-economic infra-structure, etc. Decommissioning, on the other hand, is an attempt to restore things to their original condition, which requires a much smaller commitment of resources than did building and operating the facility.

A major environmental consequence of decommissioning, other than radiation dose and dollar cost, is the commitment of land area to the disposal of radioactive waste. Estimates are shown in Table 5.4-1 of the low-level waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. The volume for ENTOMB does not include the volume of the entombing structure or of the wastes entombed within it. The entombing structure is in effect a new radioactive waste burial ground, separate and distinct from the ones in which the wastes in Table 5.4-1 are buried.

If shallow-land burial of radioactive wastes in standard trenches is assumed, then a burial volume of 18,900 m^3 of radioactive waste can be accommodated in less than 2 acres. The two acres is not large in comparison with the 1,160 acres used as the site of the reference BWR.

It is likely that certain highly activated components of the reactor and its internals will be placed in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very long half-lives of ^{59}Ni and ^{94}Nb. Only approximately 11 m^3 of material would be involved, but deep geologic disposal would add approximately $850,000 to the cost of decommissioning and would require approximately 228 m^3 of waste disposal space. This cost has been included in the costs of decommissioning shown in Table 5.3-1.

PNL considered accidental releases of radioactivity both during decommissioning during transport of wastes and the results are presented in Table 5.4-2. Radiation doses to the maximum-exposed individual from accidental airborne radioactivity releases during decommissioning operations were calculated to be quite low. Radiation doses to the maximum-exposed individual from accidental radioactivity releases resulting from transportation accidents were calculated to be low for the most severe accident.

TABLE 5.4-1. Burial Volume of Low-Level Radioactive Waste and Rubble for the Reference BWR

Decommissioning Alternative		Volume (m^3)
DECON		18 900
SAFSTOR		
Deferred Decontamination[b] following Safe Storage for:	10 Years	18 900
	30 Years	18 900[c]
	50 Years	1 780
	100 Years	1 670
ENTOMB[a]		
Internals Included		8 046
Internals Removed		8 420

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[a] Volume of entombing structure and the wastes within are not included.

[b] Radioactive wastes from preparations for safe storage are small in comparison to those from deferred decontamination.

[c] Although, in actuality, there is a more gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

Other environmental consequences of decommissioning are minor compared to the environmental consequences of building and operating a BWR. Water use and evaporation at the rate of as much as 27 x 10^6 m^3/yr ceased when the reactor ceased operation. Total water use for decommissioning should not exceed 18 x 10^3 m^3. The number of workers on site at any time will not be much greater than when the BWR was in operation and will be much less than when the BWR was under construction. The transportation network is already in place, but will require some maintenance if the SAFSTOR mode is selected.

Disturbance of the ground cover need not take place to any appreciable extent except for filling holes and leveling the ground following removal of underground structures, unless extended operation of the plant has resulted in contamination of the ground around the plant. Plowing of the ground would generally result in lowering contamination levels to that acceptable for releasing the site for unrestricted use, except for a few more highly contaminated areas which would have to be removed. In this case, soil to depth of several centimeters and some paving may have to be removed, packaged, and shipped to a disposal facility before the site can be released for unrestricted use.

The biggest socio-economic impact will have occurred before decommissioning started, at the time the plant ceased operation and the tax income created by the plant disappeared. No additional public services will be required because the decommissioning staff will be approximately the same size as the operating staff; although in the case of deferred decontamination, the decontamination staff will be larger than the surveillance staff.

5.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

From careful examination of Tables 5.3-1 and 5.3-2 it appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a BWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger occupational radiation dose is considered of marginal significance to health and safety, and therefore, DECON would be considered the more

TABLE 5.4-2. Summary of Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases during BWR Decommissioning and Transportation of Wastes

Incident	Total Atmospheric Release[b] (Ci/hr)	Radiation Dose to Lung (in rem) from: DECON		SAFSTOR		ENTOMB		Occurrence[a]
		First-Year	Fifty-Year	First-Year	Fifty-Year	First-Year	Fifty-Year	
Severe Transportation Accident	2.0×10^{-2}	9.0×10^{-2}	2.0×10^{-1}	9.0×10^{-2}	2.0×10^{-1}	9.0×10^{-2}	2.0×10^{-1}	Low
Explosion of LPG Leaked from a Front-end Loader	8.6×10^{-3}	7.9×10^{-5}	1.5×10^{-4}	N/A[c]	N/A	N/A	N/A	Low
Vacuum Filter-Bag Rupture	8.5×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	Medium
Minor Transportation Accident	5.0×10^{-4}	2.2×10^{-3}	4.5×10^{-3}	2.2×10^{-3}	4.5×10^{-3}	2.2×10^{-3}	4.5×10^{-3}	Low
Contamination Control Envelope Rupture	1.4×10^{-4}	1.0×10^{-6}	1.9×10^{-6}	N/A	N/A	N/A	N/A	High
Oxyacetylene Explosion	1.2×10^{-4}	8.7×10^{-7}	1.6×10^{-6}	N/A	N/A	N/A	N/A	Medium
Contaminated Sweeping Compound Fire	1.1×10^{-6}	1.1×10^{-7}	2.3×10^{-7}	1.1×10^{-7}	2.3×10^{-7}	1.1×10^{-7}	2.3×10^{-7}	Medium
Gross Leak During Loop Chemical Decontamination	1.0×10^{-6}	9.8×10^{-8}	2.1×10^{-7}	9.8×10^{-8}	2.1×10^{-7}	9.8×10^{-8}	2.1×10^{-7}	Low
Filter Damage from Blasting Surges	1.3×10^{-7}	1.2×10^{-9}	N/A	N/A	N/A	N/A	N/A	Medium
Combustible Waste Fire	6.0×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	High
Detonation of Unused Exposives	4.8×10^{-10}	4.4×10^{-12}	8.6×10^{-12}	N/A	N/A	N/A	N/A	Medium

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(a) The frequency of occurrence considers not only the probability of the accident, but also the probability of an atmospheric release of the calculated magnitude. The frequency of occurrence is listed as "high" if the occurrence of a release of similar or greater magnitude per year is $>10^{-2}$, as "medium" if between 10^{-2} and 10^{-5}, and as "low" if $<10^{-5}$.

(b) All atmospheric releases are assumed to occur during a 1-hr period, for comparison purposes.

(c) N/A = Not applicable.

preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR.

Either ENTOMB option requires indefinite dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay so this option is not viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory uncertainty after the long entombment time period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

It is of interest to consider the cummulative impact of decommissioning all existing and planned BWRs. In 1979 there were 25 BWRs in operation with a total electric-power producing capacity of 18,000 MWe. The environmental impact of decommissioning these 25 reactors will be approximately 16 times the impact of decommissioning the 1155 MWe reference reactor discussed here. This impact will increase as the number of BWRs increases, although one might expect some mitigation of the impact of decommissioning based on decommissioning experience or if future reactors are sited near waste disposal facilities or in multiple reactor sites (see Section 13).

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2. AEC-Elk River Reactor Final Program Report, COO-651-93. United Power Association, Elk River, Minnesota, revised November 1974.

3. T. D. Murphy, N. J. Dayem, J. S. Bland and W. J. Pasciak, Occupational Radiation Exposure at Light Water Cooled Power Reactors 1969-1975, NUREG-0109, August 1976, Table 1.**

4. E. B. Moore, Jr., Facilitation of Decommissioning Light Water Reactors, NUREG/CR-0569, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, December 1979.*

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the National Technical Information Service.

6.0 URANIUM MILL AND URANIUM MILL TAILINGS PILE

In 1978 the United States Congress passed the Uranium Mill Tailings Radiation Control Act (see Section 1.4.1). In September 1980, the NRC published a final EIS on uranium milling.(1) Based on the conclusion of the EIS and the requirements of the Act, the NRC amended its regulations in October 1980 to specify licensing requirements for uranium mills and mill tailings. The reader is referred to these documents for information on decommissioning uranium mills and tailings piles.

REFERENCES

1. Final Generic Environmental Impact Statement on Uranium Milling, U.S. Nuclear Regulatory Commission, NUREG-0706, September 1980. Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

7.0 FUEL REPROCESSING PLANT

A fuel reprocessing plant (FRP) is a facility for reclaiming plutonium and uranium from spent nuclear reactor fuel, so that the reclaimed plutonium and uranium can be later refabricated into new fuel elements. For the purpose of this section, it is assumed that the plant is to be operated 30 to 40 years. It is also assumed that any accidental releases of radioactive material are cleaned up immediately following the event. The generic site of a fuel reprocessing plant is described in Section 3.1.

This section is based primarily on a detailed study(1) of the decommissioning of a fuel reprocessing plant conducted by Pacific Northwest Laboratory (PNL) for the NRC. In this study, PNL selected the Barnwell Nuclear Fuel Plant (BNFP), located in Barnwell, South Carolina, as the reference FRP and assumed it to be located at the generic site. Although the Barnwell facility has never operated as an FRP, its design is considered to have characteristics typical of those present in any future FRPs. PNL then developed and reported information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life.

7.1 DESCRIPTION OF FUEL REPROCESSING PROCESS AND FACILITY

7.1.1 Process Description

The reference plant uses the Purex process to recover plutonium and uranium from irradiated LWR fuels. A simplified block flow diagram of this process is shown in Figure 7.1-1.

The irradiated fuel is received in heavily shielded casks and is unloaded and stored underwater in the fuel receiving and storage station (FRSS). When ready for processing, each fuel assembly is transferred to the main process building where it is partly disassembled, chopped into pieces up to 10 cm long and dropped into a dissolver vessel where the fuel materials are dissolved with nitric acid. The undissolved fuel cladding hulls are packaged and taken to a bunker-type storage area onsite.

The nitric acid-fuel solution is then subjected to a solvent extraction process where the uranium, plutonium, and fission products are separated into individual streams, and the uranium and plutonium are purified and converted to uranium hexafluoride and plutonium oxide for offsite shipment. The fission products are stored in underground water-cooled tanks for about 5 years and then solidified for disposal in a federal facility.

7.1.2 Plant Description

The major facilities included in the reference reprocessing plant are: 1) the fuel receiving and storage station, 2) the main process building, 3) the high- and intermediate-level liquid waste storage area, 4) the waste solidification plant, and 5) the radioactive auxiliary service areas. Detailed descriptions of these facilities are presented in Reference 1.

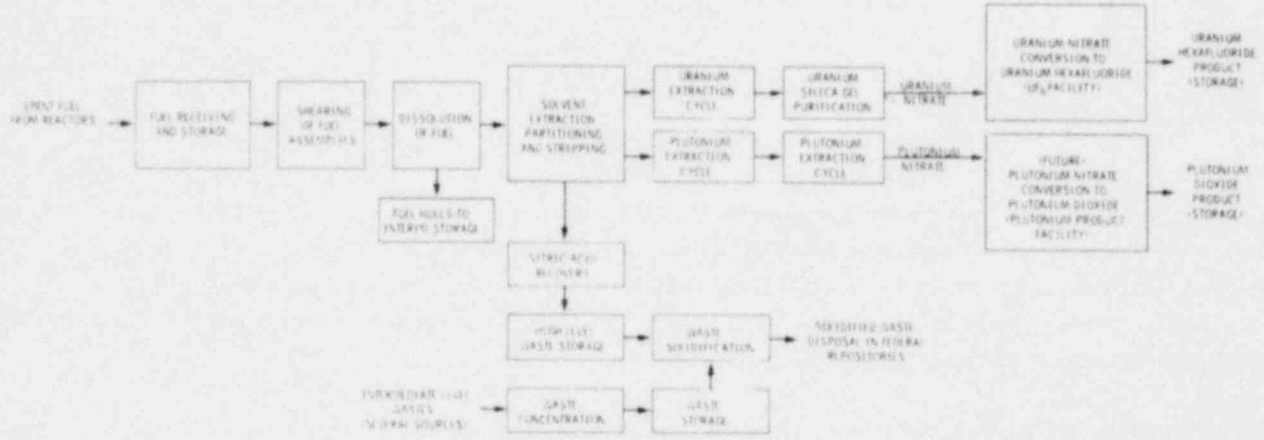

FIGURE 7.1-1. Simplified Process Flow Diagram for a Fuel Reprocessing Plant

The following is a listing of various operating parameters of the reference FRP:

Inputs to the FRP

Spent Fuels from Light Water Reactors (Zircaloy or stainless steel cladding) with the following content:

- UO_2 (up to 3.5 % enrichment when input to the reactor)
- UO_2-PuO_2 (Pu up to equivalent of 3.5% ^{235}U when input to the reactor)
- Special fuels up to 5% initial enrichment under special operating conditions

Spent Fuel Burnup[a]:

- From PWRs, average exposure of 31,800 MWD/MTHM (peak of 33,000 MWD/MTHM)
- From BWRs average exposure of 25,300 MWD/MTHM (peak of 26,000 MWD/MTHM)
- For total input, average total exposure of 29,300 MWD/MTHM

Spent Fuel Out-of-Reactor Time prior to FRP input:

- Minimum of 90 days prior to receipt at FRP
- Minimum of 1.5 years before reprocessing at FRP[a]

FRP Reprocessing Capacity (in MT of Spent Fuel)

- 1,500 MT/yr (30-yr lifetime)[a] average capacity
- 5 MT/day peak capacity

Products of Reprocessing

- Uranyl nitrate solution (converted to UF_6 for shipment from FRP to burial grounds)
- Plutonium nitrate solution (converted to PuO_2 for shipment from FRP to burial grounds)[a]

Wastes Resulting from Reprocessing

- High-Level and intermediate-level wastes stored on an interim basis as liquids in underground tanks.
- High and intermediate level liquid wastes converted within 5 years to a vitrified solid and shipped offsite to a Federal repository.

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[a] Processing characteristics listed are different from those postulated for near-term operation of BNFP. The information presented is currently expected to be representative of long-term operating characteristics at a plant such as BNFP.

- Fuel cladding hulls, failed equipment and other solid wastes stored onsite on an interim basis in concrete or stainless steel containers in engineered underground storage prior to shipment offsite for disposal.

Effluents from Reprocessing During Normal Operation

- Gases (only routine radioactive effluents are indicated):

  ^{85}Kr discharged up main stack (100 meters tall) Majority of tritium and ^{14}C discharged to main stack

  Excess water discharged up main stack as vapor
- Heat rejected to cooling tower via closed loop heat exchangers
- Process liquid wastes with low contamination diluted and discharged to river.

7.1.3 Estimates of Radioactivity Levels at FRP shutdown

Estimates of radioactivity levels in the reference fuel reprocessing plant after reprocessing operations have been terminated (all spent fuel removed) and final operational cleanout flushings of the process areas have been completed are summarized in Reference 1.

7.2 FUEL REPROCESSING PLANT DECOMMISSIONING EXPERIENCE

To date, there has been no experience in the decommissioning of a commercial FRP. Federal facilities at the Hanford, Savannah River, and Oak Ridge sites that have been involved with the reprocessing of irradiated fuels have been decontaminated and their equipment disassembled.$^{(2)}$ A substantial amount of this information is directly relatable to decontamination of future fuel reprocessing plants.

The Nuclear Fuel Services (NFS) plant in West Valley, New York, is the only commercial reprocessing plant that has operated in the United States (although it is not currently operating). The NFS situation is not directly translatable to the present or projected nuclear power industry because a national policy (10 CFR 50, Appendix F) requiring the solidification of high-level waste was not established until 1971, well after the plant began operation. Therefore, since NFS has its reprocessing high-level wastes stored in large underground tanks in slurry form (similar to the practices followed at the Hanford and Savannah River sites), the costs of decommissioning this plant are expected to be higher than that of newer FRPs.

7.3 DECOMMISSIONING ALTERNATIVES

Once a fuel reprocessing plant has reached the end of its useful operating life, it must be decommissioned. As discussed in Section 2.3 this means safely removing the facility from service and disposing of all radioactive materials in excess of levels which would permit unrestricted use of the facility. Several alternatives are considered here as to their potential for satisfying this general requirement for decommissioning. These alternatives include DECON, SAFSTOR, and ENTOMB. The disposition of the nonradioactive buildings and facilities is left to the discretion of the facility owner and is not part of the decommissioning procedure. This section discusses the decommissioning alternatives evaluated for the FRP.

7.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as the 5 years estimated for decommissioning after the end of facility operation.

DECON is advantageous because it allows for termination of the NRC license shortly after cessation of facility operations and removes a radioactive site. DECON is advantageous if the site is required for other purposes, if the site is extremely valuable, or, if for some reason the site must be immediately released for unrestricted use. It is also advantageous in that the facility operating staff is available to assist with decommissioning and that continued surveillance is not required. An important disadvantage is the higher occupational radiation dose which occurs during DECON compared to the other alternatives.

Three important radiation exposure pathways need to be considered in the evaluation of the radiation safety of normal FRP decommissioning operations: inhalation, ingestion, and external exposure to radioactive materials. For reasons similar to that discussed for PWRs in section 4.3.1, during decommissioning the dominant exposure pathway to workers is external exposure while for the public the dominant exposure pathway is inhalation. During the transport of radioactive waste, the dominant exposure pathway is external exposure for both transportation workers and the public. A summary of the doses resulting from these pathways is presented in Table 5.3-2.

Occupational Radiation Dose

The occupational radiation dose from external exposure to radioactive materials, not including transportation of radioactive waste, is estimated to be about 512 man-rem over the 5 year period of DECON. Occupational radiation doses were calculated by PNL from estimated radiation levels in the various areas of the reference FRP and from man-hour estimates for performing the decontamination operations. Table 7.3-2 gives the estimated occupational external radiation exposure for DECON.

The reference FRP was designed to store high level liquid waste (HLLW) for five years prior to solidification and then to store the solidified waste five years prior to shipment to a federal waste repository. It is expected that any future FRPs would be designed to solidify the HLLW continuously within the process building, and store only solidified waste. Therefore, future plants would use a few smaller tanks instead of the large underground HLLW storage tanks and separate waste solidification plant. This would reduce the decommissioning occupational radiation exposure and costs by between 40 to 50 percent.

Public Radiation Dose

The inhalation radiation dose to the public resulting from radionuclide releases during DECON, not including doses during transportation of radioactive waste, is estimated to be 10.2 man-rem (50-year population dose commitment to the whole-body). This radiation dose is very small compared to the background radiation exposure normally received by members of the public. Details of the methods used for calculation of doses are found in Reference 1.

Public Radiation Dose from Postulated Accidents During DECON

DECON procedures were examined and potential accidents postulated that could lead to the release of radioactive materials. The largest radiation dose to the maximum-exposed individual from a postulated accident during DECON is the failure of the ventilation system HEPA filter during the high-level waste tank chemical decontamination operations. Approximately 60 mCi of radioactivity are assumed to be released directly to the atmosphere. This release results in a maximum annual dose in the first year of 15 mrem to the lung and a 50-year dose commitment of 160 mrem to the bone of the maximum-exposed individual.

Transportation Safety During DECON

Radioactive waste generated during the decontamination of an FRP must be packaged and shipped according to prescribed federal regulations to an offsite repository. These wastes include transuranic (TRU) wastes that are shipped by rail to a Federal repository and non-TRU wastes that are shipped by truck to a commercial shallow-land burial ground. A summary of the wastes generated and shipped is given in Table 7.3-1.

TABLE 7.3-1. Packaging and Shipping Information for Wastes Generated from DECON[(a)]

Shipping Method	Volume, m^3	Weight, kg	Number of Containers	Number of Shipments
Rail (TRU wastes)	4 600	3.7×10^6	3 200	180
Truck (non-TRU wastes)	3 100	2.3×10^6	2 500	160

[(a)] Initial chemical decontamination wastes account for approximately 5% of the total volume, 9% of the total shipments, and 99.9% of the total radioactivity.

The estimated radiation doses due to external exposure from rail and truck transport of radioactive wastes are 20 man-rem to the transportation workers and 9 man-rem to the public.

The release of radioactive material from transportation accidents is estimated to be small. The more probable transportation accidents result in no release or one that is very small. For a severe truck accident, a hypothetical maximum-exposed individual located at 100 m is estimated to receive a 50-year dose commitment to the bone of 11 rem; however, this type of accident has a very low probability of occurrence.

7.3.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a FRP in such condition that the risk to safety is within acceptable bounds and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

Generally, the purpose of SAFSTOR is to permit residual radioactivity levels to decay to levels that will reduce occupational radiation exposure during decontamination. As indicated in Table 7.3-2 most of the occupational dose reduction due to decay occurs during the first 100 years after shutdown with less dose reduction thereafter. The public dose which is small to begin with, also experiences most of its reduction during the first 100 years. Hence, in contrast to DECON, to take advantage of this dose reduction, the safe storage period could be as long as 30 to 100 years. The end result is the same as for DECON: release of the site and any remaining structures for unrestricted use.

SAFSTOR is advantageous in that it results in reduced occupational radiation exposure and in situations where overriding land use considerations do not exist. Disadvantages are that the licensee is required to maintain a material license and to meet its requirements at all times during safe storage thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantageous are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the deferred decontamination.

The several subcategories of SAFSTOR are given in Section 2.3.2. They are discussed in detail here as they pertain to FRP decommissioning.

TABLE 7.3-2. Summary of Radiation Safety Analysis for Decommissioning the Reference FRP (Man-rem)

	DECON	SAFSTOR (Passive)				SAFSTOR (Custodial)				ENTOMB
		10 Years	30 Years	100 Years	200 Years	10 Years	30 Years	100 Years	200 Years	
Occupational Safety										
Decontamination Operations	512	426(a)	296(a)	124(a)	∼85(a)	423(a)	290(a)	113(a)	∼73(a)	170(a)
Transportation	20	17	12	5	∼1	17	12	5	<2	5
Continuing Care	---	2	4	9	14	13	31	61	78	neg.
Total Occupational Exposure	532	445	312	138	100	453	333	179	∼153	175
Public Safety(b)										
Decontamination Operations	10	8	5	2	<1	8	5	2	<1	2
Transportation	9	7	5	2	<1	7	5	2	<1	1
Continuing Care	--	neg.(c)	neg.(c)	neg.(c)	neg.(c)	neg.(c)	neg.(c)	neg.(c)	neg.(c)	neg(c)
Total Public Exposure	19	15	10	4	<2	15	10	4	<2	3

(a) The radiation exposures for the preparation for passive and custodial safe storage are 81 and 69 man-rems, respectively and are included in the exposures for Decontamination Operations.

(b) Radiation doses from postulated accidents are not included.

(c) Neg. = negligible. Radiation doses to the public from normal continuing care activities are not analyzed in detail, but are expected to be significantly smaller than those from decontamination operations.

Preparation for Safe Storage

Custodial SAFSTOR requires a minimum cleanup and decontamination effort during preparation for safe storage, followed by a period of continuing care with the active protection systems (principally the ventilation system) kept in service throughout the storage period. Safe storage preparation procedures for passive and hardened safe storage are the same as those for custodial safe storage, with the exception of the following additional activities:

- sealing all entrances to the radioactive portions of the facility, using welding techniques
- deactivating the ventilation systems
- deactivating all cranes and viewing windows.

Hardened safe storage requires slightly more extensive sealing of the structures than passive safe storage; however, the cost increase is estimated to be small. Thus, passive and hardened SAFSTOR are considered the same for this assessment.

The occupational radiation doses from passive and custodial safe storage preparation, not including transportation, are estimated to be 81 and 69 man-rem, respectively, and are given in Table 7.3-2. The extra labor to prepare for passive storage results in the slightly higher dose.

The estimated inhalation radiation doses to the public from the release of radionuclides during both passive and custodial safe storage preparation are estimated to be 0.006 man-rem (bone dose) to the population. This dose is much below natural background radiation exposure.

The maximum postulated accident for passive and custodial safe storage preparation is a fire in the ventilation system resulting in a maximum annual lung dose in the first year of 0.006 mrem and a 50-year lung dose commitment of 0.008 mrem.

Estimated routine radiation doses from rail and truck transport of radioactive wastes from either passive or custodial storage preparations are 3 man-rem to transportation workers and 1.4 man-rem to the general public.

Safe Storage (Continuing Care)

Following completion of safe storage preparation, the facility is placed in a period of safe storage (continuing care). This safe storage consists of surveillance and maintenance, designed to ensure that the facility remains in a condition that poses minimum risks to the public. This phase includes routine inspections, preventive and corrective maintenance on operating equipment, and a regular program of radiation, effluent, and environmental monitoring. The status of all safety-related equipment is monitored throughout the continuing care period. Passive and custodial continuing care doses are listed in Table 7.3-2.

The release of radionuclides from accidents during the continuing care period is negligible. The combination of the low probability of the initiating events and the immobility of the FRP radionuclide inventory minimizes the effect of potential accidents during this period.

Deferred Decontamination

Deferred decontamination to residual levels permitting unrestricted use of the facility takes place after a number of years of safe storage. This decontamination is more thorough than the preliminary decontamination which was a part of the preparations for safe storage. The decontamination procedures are essentially the same following each of the different SAFSTOR modes; however, the steps necessary following passive safe storage are more extensive. The additional activities include:

- removal of entrance barriers to contaminated areas
- reactivation of utilities, cranes, and manipulators
- installation of filters and reactivation of the ventilation systems.

The principal advantage of deferred decontamination is that radioactive decay takes place during the continuing care period. Table 7.3-2 shows that decontamination at a deferred time reduces the occupational radiation exposure by a substantial amount. Deferred decontamination would also reduce the radiation dose commitment for public exposure as shown in Table 7.3-2.

The radiation dose from transportation for deferred decontamination for both public and occupational exposures is expected to decrease because of radionuclide decay and also because of a reduction in materials needing transportation. A 100-year delay would result in a radiation dose reduction of about 75%. These doses are shown in Table 7.3-2.

7.3.3 ENTOMB

The ENTOMB alternative requires the use of a structure to hold or confine the radioactivity until such time as it has decayed to levels which permit release of the facility for unrestricted use. This structure would include concrete and metal barriers which would prevent the escape of radioactivity and prevent deliberate or inadvertant intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radionuclides present. Sections of the FRP structure that contain highly radioactive material have heavily reinforced concrete walls 5- to 7-ft thick that would be easily entombed. However, the FRP contains long-lived transuranic radionuclides such as ^{239}Pu with a half-life of 24,390 years and the entombed structure would in effect become a new surface high level waste disposal site. This would be an undesirable situation in that it would be contributing to the problems associated with increased numbers of high level waste disposal sites. Moreover, the entombed structure would require surveillance in perpetuity which is well beyond the time that the required institutional control could be expected to be effective (approximately 100 years is considered to be consistent with recommended EPA policy on institutional control reliance for radioactivity confinement). Although the ENTOMB option does not appear viable for the reasons given, it will be discussed for comparative perspective with the other options.

ENTOMB is estimated to result in occupational doses of 170 man-rem, as compared to 512 man-rem for DECON. The public dose from both plant releases and transportation would also be similarly reduced, since the bulk of the highly radioactive equipment is not disturbed. These are shown in Table 7.3-2.

Compared to DECON, ENTOMB effects a large saving in the packaging, shipping, and burial of wastes generated during the decommissioning. The burial waste saving is illusory in that the entombed structure becomes a high-level waste burial ground and a license maintained for the site. Table 7.3-3 gives the volume, weight, number of containers, and shipments for entombment.

TABLE 7.3-3. Packaging and Shipping of Wastes Generated from ENTOMB[(a)]

Shipping Method	Volume, m^3	Weight, kg	Number of Containers	Number of Shipments
Rail (TRU wastes)	1 150	0.6×10^6	1 500	100 cars
Truck (non-TRU Wastes)	2 066	1.3×10^6	1 560	100 trucks

(a) The volume of the entombed wastes and of the entombing structure is not included.

Since the number of shipments has been reduced, the probability of transportation accidents and their severity has also been reduced as compared to DECON.

7.3.4 Site Decommissioning

The residual contamination of the FRP site resulting from past operation and subsequent decommissioning is expected to be very low. This is as a result of continuous site surveys and the immediate removal of any contamination found during the life of the facility. Site cleanup is expected to be minimal, however, this will be confirmed by the radiation survey.

7.3.5 Summary of Radiation Safety

An advantage of DECON is that it results in the release of the site for unrestricted use within about 5 years after shutdown of plant operations. However, DECON has higher estimated occupational radiation exposure (512 man-rem) than the other alternatives. Depending on the length of the continuing care period, both passive and custodial SAFSTOR can result in an occupational dose reduction the magnitude of which is considered to be of marginal significance in terms of health and safety. (see Table 7.3.2). ENTOMB results in lower occupational exposures than DECON and 30-year SAFSTOR but higher exposures than 100-year SAFSTOR.

As shown in Table 7.3-2, radiation doses to the public from decommissioning operations and transportation of contaminated materials are all low, with a maximum of 19 man-rem due to DECON. The maximum postulated accident is estimated to give the maximum-exposed member of the public a 50-year dose commitment of 8.8 rem.

In summary, the radiation dose to the public is estimated to be quite low and to have little impact compared to natural background radiation. For decommissioning workers, DECON results in larger radiological impact than the other alternatives. Reductions in this dose can be brought about by use of 30-year or 100-year SAFSTOR. 100-year SAFSTOR results in occupational exposures lower than that of ENTOMB and also results in release of the facility for unrestricted use which ENTOMB would not.

7.3.6 Decommissioning Costs

An estimate of the costs of decommissioning the FRP by each of the principal alternatives is presented below. These costs are summarized and compared in Section 7.3.6.2.

7.3.6.1 Detailed Costs

Reference 1 presents a discussion of decommissioning costs and their bases. Costs are included for 1) direct labor and subcontractor activities, 2) equipment and materials, 3) packaging, transportation, and disposal of contaminated waste, and 4) utilities, services, and other overheads. The details presented in Reference 1 include breakdowns for support staff labor, decommissioning worker labor, subcontractor activities, equipment and materials, shipping, waste disposal and utilities and taxes.

The basic cost estimates presented assume relatively efficient performance of the decommissioning activities. A 25% contingency is added to the cost estimate totals as an allowance for unforeseen problems or scheduling delays that may arise during the decommissioning.

7.3.6.2 Summary of Costs

Table 7.3-4 summarizes the estimated costs in 1978 dollars for the decommissioning alternatives. As shown in the table, the costs for DECON and 10-year SAFSTOR (passive) are essentially the same. All SAFSTOR modes increase in cost with increasing years of continuing care. The continuing care cost following preparation for custodial and passive safe storage are estimated to be $800,000 and $184,000 per year, respectively. In the case of passive safe storage, the surveillance effort is expected to gradually decrease over the years until, at about 50 years, the estimated cost is expected to be in the range of $33,000 to $50,000 per year. Costs for deferred decontamination after custodial and passive safe storage are estimated to be $56 and $57 million, respectively. When continuing care costs in perpetuity are included in the ENTOMB decommissioning alternative, it becomes the most costly.

TABLE 7.3-4. Summary of Estimated Costs for Decommissioning a Fuel Reprocessing Plant (1978 $ millions)

Item	DECON	SAFSTOR (passive)				SAFSTOR (custodial)				ENTOMB
		10 Years	30 Years	100 Years	200 Years	10 Years	30 Years	100 Years	200 Years	
Initial Decommissioning	76	24	24	24	24	23	23	23	23	37
Continuing Care[a]	--	2	6	18	22	8	26	88	6	.04/yr.
Deferred Decontamination	--	57	57	57	57	56	56	56	56	--
Total Costs (rounded)	76	83	87	99	103	88	105	167	255	37[b]

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[a] Continuing care costs for passive storage are estimated to decline with the years to about $40.000 per year for the last 100 years; $18 million for the first 100 years is a conservative estimate.

[b] Add $40,000 per year for surveillance, monitoring, and maintenance.

Deferred decontamination is a comparatively large cost because it requires additional costs to refurbish auxiliary facilities, to reinstitute a trained decommissioning organization, and to provide a new safety analysis and an additional license application. Other costs of deferred decontamination are lower than for DECON due to the decay of much of the radioactivity. As can be seen from Table 7.3-4, continuing care costs become more significant with time.

ENTOMB requires some surveillance of the approximately 1-2 acre in perpetuity, with costs estimated to be about $40,000 per year. An initial look at Table 7.3-4 makes ENTOMB appear to be the lowest cost of the four options. However, when the cost of perpetual care is included (for a 24,390 year half-life radionuclide such as Pu-239) this advantage soon disappears. The costs of initial decommissioning for ENTOMB, as presented in Table 7.3-4, is 50% of those for DECON and is largely a result of reductions in shipping and waste disposal cost. It should be emphasized that these savings in waste disposal costs can be misleading because the entombment structure has now become a high level waste repository. The entombment procedure also requires about one-half the time necessary for DECON using the same work force, thus, reducing the labor costs by about 40%. The cost of the concrete for entombment and the labor to emplace it are combined and estimated to be about $2.5 million.

Waste management costs represent about 50% of the total cost for decontamination of the reference FRP. Waste disposal costs for transuranic wastes, in turn, represent about 60% of the waste management costs. Since waste disposal costs are based on the volume of material placed in the deep geologic repository, reducing waste volumes has a significant effect in reducing decommissioning costs. Significant economic incentives exist to develop volume reduction techniques. For example, extensive use of electropolishing, which has the potential to decontaminate metallic wastes to releasable radioactive contamination levels or to levels that permit their disposal in shallow-land burial grounds, may offer cost reductions.

Decontamination of the liquid waste storage system represents about one-third of the total decontamination costs. Alternative reprocessing plant designs might not employ large liquid waste storage systems. These designs would have a significant decommissioning cost advantage (40 to 50%) over the design of the reference plant.

It is assumed that radioactive contamination levels on the site from routine releases during facility operation do not require extensive site cleanup operations during decommissioning to meet the limits for release of the FRP for unrestricted use. A preliminary estimate of the costs to perform these activities, should they be required, is $65,000. This would not appreciably change the decommissioning cost totals presented in Tables 7.3-4.

7.4 ENVIRONMENTAL CONSEQUENCES

The decommissioning of an FRP will have few negative environmental consequences. By definition, the decommissioning of any nuclear facility is the removal of radioactive material to levels which are low enough to permit the facility to be released for unrestricted use. The decommissioning alternative to be chosen depends to a large extent on the radiation dose and cost evaluations, on desired future use of the site, and on the time period involved.

The summaries of radiation safety and decommissioning cost analyses are given in Sections 7.3.5 and 7.3.6, respectively.

Demolition of remaining buildings (assuming prior decontamination to a level permitting unrestricted use of the FRP) is an optional owner and/or local government choice. Its major environmental impact on the surrounding population will be the resulting increase in noise level within the immediate vicinity of the plant (about 1 mile), primarily because of the use of explosives. However, most of this noise will be generated within the process building and will be muffled by the building until the final removal of the building shell.

7.4.1 Wastes

The management of wastes (i.e., vitrified, chemical decontamination solutions, contaminated equipment and materials, and contaminated trash) resulting from decommissioning is an important factor in the cost and environmental impact of decommissioning. The large volumes of waste generated during DECON, as shown in Table 7.4-1, require a large expenditure of money and energy. Complete decontamination of an FRP requires about 0.4 hectare (1 acre) of land for final storage of the contaminated materials removed from the site. The high-level radioactive and TRU wastes will require about 4,600 m^3 in an expensive deep geologic disposal facility. This is equivalent to 163,500 cubic feet mined from either salt or basalt. The low-level and non-TRU wastes will require about 0.16 hectares (0.4 acre) of shallow land burial area. These are considered irretrievable uses of land.

ENTOMB as shown in Table 7.4-1, results in a large reduction (about 75% of DECON) in wastes to be buried in deep geologic storage. However, these procedures convert the entombed structure to a high-level waste burial ground and the volume of this waste is not included in Table 7.4-1. Wastes for shallow-land burial are also reduced, but to a smaller extent (about 35%). The entombed structure becomes a waste burial ground with the inclusion of high- and low-level waste.

The volumes of waste for both passive and custodial safe storage represent the preparation stage only. Deferred decontamination wastes increase each of these to values nearly that of DECON. However, although the overall waste volume may remain nearly constant, the amount sent to geologic storage will decrease with time, while shallow-land burial volumes will increase. For example, if the continuing care period were extended for 100 years, there would be a reduction in radioactivity and thus the total amount of waste to be disposed of to repositories would shift from expensive deep geologic storage to shallow-land burial. These changes would result in a substantial reduction of costs and repository use.

The decommissioning of an FRP to levels which permit unrestricted use of the facility makes about 473 hectares (1,160 acres) of land available for reuse. The value recovered from decommissioning depends on the value of the reclaimed land and the need the owner has for such property during the time period under consideration.

If the plant site of about 20.4 hectares (50 acres) is restored to its original native condition it will increase the natural habitat for flora and fauna by a relatively small amount. This is a favorable environmental impact, but one that is relatively insignificant.

An additional effect of decommissioning is that the decontamination of an FRP will require the use of expendable tools and materials that will be discarded as waste and will cost as much as $4.0 million.

7.4.2 Nonradiological Safety Impacts

The nonradiological hazards involved in the decommissioning of an FRP were reviewed on the basis of hazards to be found in both the chemical and construction industries. These estimates are calculated to be conservative.

Potential chemical pollutants that could be released during the various decommissioning alternatives were examined and found to be insignificant. The small quantities of hazardous chemicals used and the low likelihood of their dispersal into the environs indicate that potential chemical pollutants from decommissioning operations do not pose a significant public hazard.

The potential lost-time injuries and fatalities are based on AEC/DOE operations data. Table 7.4-2, gives the lost-time injuries and the fatalities estimated for each decommissioning mode. The maximum potential for lost-time injuries and fatalities (1.9 and 0.01, respectively) is during the decontamination operations when the maximum amount of heavy equipment is being removed from its position, cut, boxed, and shipped to appropriate storage.

7.4.3 Socio-Economic Impacts

The major societal impacts occur prior to decommissioning with the shutdown of the plant. The shutdown of the plant and DECON will reduce the work force from about 300 to 50 people over about a 2-year period and the 50 person decommissioning force will be reduced to near zero in 3 to 6 years. Thus, the total reduction in force will take place over a minimum period of 5 years and this should tend to mitigate the adverse impact of loss of jobs and income to the regional community. Since the planning stage preceding the shutdown will require about two years, the community will have an additional two years to plan for the reduction in jobs. Therefore, the impact from job loss (income loss of about $3.5 to $4.0 million annually) due to plant shutdown will be small because of the period of time for the action to take place. Decommissioning tends to mitigate the impacts due to plant shutdown.

Tax revenues will also be lost to the local communities and to the state, but here again, the impact is spread over a period of time and as employment reduces and people leave the area, public services will also reduce. Thus, decommissioning tends to mitigate the impacts of plant shutdown.

TABLE 7.4-1. Radioactive Wastes resulting from Decommissioning a Reference FRP

	Wastes as Packaged							
	DECON		Passive SAFSTOR(a)		Custodial SAFSTOR(a)		ENTOMB(b)	
Disposition of Waste	Volume, m^3	Disposal Cost, Millions of $	Volume, m^3	Disposal Cost, Millions of $	Volume, m^3	Disposal Cost, Millions of $	Volume, m	Disposal Cost, Millions of $
Deep Geologic Disposal	4 600	30.0	310	8.0	210	8.0	1 150	16.5
Shallow-Land Burial	3 100	1.3	180	0.07	180	0.07	2 070	0.8
Totals	7 700	31.3	490	8.1	390	8.1	3 220	17.3

(a) Does not include deferred decontamination.

(b) Does not include volume of entombing structure or entombed wastes.

7.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

Primary parameters that affect the selection of a decommissioning alternative are the radiation doses and the economic costs. These are summarized in Table 7.4-3.

Advantages of DECON are that the site and facility can be released for unrestricted use 5 years after the shutdown of the plant and that the cost for DECON is less than for SAFSTOR, and therefore, DECON is considered to be a preferable alternative since occupational dose reduction by SAFSTOR is of an amount considered of marginal significance to health and safety. Both 30-year SAFSTOR and 100-year SAFSTOR may be reasonable options for reducing occupational exposure since additional radioactive decay occurs after 30 years. In 100-year SAFSTOR, the occupational dose rates have decayed to about 30% of DECON and the costs, although increased by 30% over the 100-year period are still reasonable when evaluated against the reduced occupational dose.

ENTOMB is indicated as the least appropriate option. When the cost of surveillance in perpetuity is considered for the high-level waste repository that would in effect be created, this becomes the most costly decommissioning mode. Moreover, it contributes to problems associated with increased numbers of high-level waste sites. The savings in decommissioning dose that this alternative might offer over DECON could equally be saved with 100-year SAFSTOR. The societal concerns of long-term surveillance have not been quantified but these concerns would tend to reduce incentives for long-term deferral of decontamination.

TABLE 7.4-2. Summary of Nonradiological Safety Impacts

Type of Safety Concern	Source of Safety Concern	Units	DECON	SAFSTOR (Passive) 10 Years	SAFSTOR (Passive) 30 Years	SAFSTOR (Passive) 100 Years	SAFSTOR (Passive) 200 Years	SAFSTOR (Custodial) 10 Years	SAFSTOR (Custodial) 30 Years	SAFSTOR (Custodial) 100 Years	SAFSTOR (Custodial) 200 Years	ENTOMB
Serious Lost-Time Injuries[a]	Decommissioning Operations	no./mode	1.7	1.9	1.9	1.9	1.9	1.75	1.75	1.75	1.75	0.85
	Transportation	no./mode	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.10
	Continuing Care	no./mode	--	0.083	0.26	0.83	1.6	0.40	1.2 4.0	8.0	---	
Fatalities(a)	Decommissioning Operations	no./mode	0.0091	0.010	0.010	0.010	0.010	0.0096	0.0096	0.0096	0.0096	0.005
	Transportation	no./mode	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.007
	Continuing Care	no./mode	--	0.0008	0.0024	0.0081	0.016	0.038	0.012	0.038	0.076	---

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(a)Estimates of lost-time accidents and fatalities for either passive or custodial safe storage preparation are 0.3 and 0.003, respectively. The transportation estimates of lost-time accidents and fatalities for either passive or custodial safe storage preparation are 0.03 and 0.002, respectively.

TABLE 7.4-3. Values of Parameters for Alternative Decommissioning Approach Comparisons

	DECON	SAFSTOR (Passive) 10 Years	SAFSTOR (Passive) 30 Years	SAFSTOR (Passive) 100 Years	SAFSTOR (Passive) 200 Years	SAFSTOR (Custodial) 10 Years	SAFSTOR (Custodial) 30 Years	SAFSTOR (Custodial) 100 Years	SAFSTOR (Custodial) 200 Years	ENTOMB
Total Cost (million $) (constant 1978 dollars)	76	83	87	99	103	88	105	167	256	37[a]
Land Area Committed (km^2)	0.0	0.12	0.12	0.12	0.12	4.7	4.7	4.7	4.7	0.0
Occupational Radiation Dose (man-rem)[b]	532	445	312	138	100	453	333	179	153	175
Potential Public Radiation Dose (man-rem)[b]	19	15	10	4	<2	15	10	4	<2	3
Potential Industrial Accidents	1.9	2.2	2.3	2.9	3.7	2.3	3.1	5.9	9.9	1.0
Serious Accidents Fatalities	0.21	0.023	0.024	0.030	0.038	0.025	0.034	0.060	0.012	0.012
Manpower Expenditures (cumulative man-years)	423	481	515	634	753	510	693	1 338	1 805	228

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[a] ENTOMB surveillance costs are estimated to be about $40,000 per year.

[b] Includes decommissioning operations, interim care, and transportation where applicable.

REFERENCES

1. K. J. Schneider and C. E. Jenkins, Technology, Safety, and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.*

2. G. J. Konzek and C. R. Sample, Decommissioning of Nuclear Facilities-- An Annotated Bibliography, NUREG/CR-0131, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1978.*

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

8.0 SMALL MIXED OXIDE FUEL FABRICATION PLANT

A small mixed oxide (MOX) fuel fabrication plant is a manufacturing facility designed and constructed for the production of (U-Pu)O_2 pellets and incorporation of these pellets into clad fuel rods. The plant also has facilities for the recovery of plutonium from unirradiated scrap materials. This section considers the environmental consequences of decommissioning a small MOX plant.

This section is based primarily on a detailed study(1) of the decommissioning of small mixed oxide fuel fabrication plant. In this study PNL selected the Cimarron Plutonium Facility located near Crescent, Oklahoma as the reference MOX plant and assumed it to be located at the generic site. The generic site is described in Section 3.1. Although not currently operating, Cimarron is considered to have characteristics related to many of the existing small MOX plants. Some operational features were added to this study to make it applicable to plants using other processes. PNL then developed and reported information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life.

8.1 DESCRIPTION OF THE REFERENCE MOX FUEL FABRICATION PLANT

The reference plant is assumed to have operated for 10 years at a production rate of 2 MT of heavy metals per year. The feed to the plant can be either the oxide powders or nitrate solutions of plutonium and uranium. The plant operation is assumed to involve either mechanical blending of the oxide powders or coprecipitation of the solutions, using ammonia. The plant consists of a single building with a floor space of 2400 m^2 that also contains offices, laboratories, and maintenance shops. Auxiliary facilities are a cooling tower, an electrical substation, effluent storage, and a gas supply. Processes include solvent extraction, ion exchange, and oxalate precipitation for recovery of dirty scrap, and a two-stage liquid waste evaporation system followed by concreting of liquid wastes. The plant uses small, criticality safe vessels located in numerous glove boxes distributed throughout nine rooms. Operation of most steps is on a batch basis.

The generic site (Section 3.1) for this plant is located in a rural area. The site occupies 470 hectares (1,160 acres) in a rectangular shape of 2 km (1.24 miles) by 2.35 km (1.46 miles). A moderate-size river runs through one corner of the site. The use of any of this site for anything besides the MOX plant is prohibited. The plant is in a restricted area of about 1.2 hectares (3 acres) within the site.

As a part of the plant operations, it is assumed that a final inventory cleanout has been performed that included disposal of process materials, chemicals, trash, scrap, scrap solutions, and contaminated solutions. Empty product, scrap, and waste handling tanks have been flushed of remaining process solutions. The dominant remaining radionuclides that will contribute to organ doses are ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{241}Am. About 23 kg of plutonium are estimated to remain in the process building following the final inventory cleanout.

8.2 MOX DECOMMISSIONING EXPERIENCE

No direct experience exists in the decommissioning of licensed MOX fuel fabrication facilities because existing plants, which are not now operating, are being held in a standby or storage status. However, several government-owned plutonium fabrication facilities have been decontaminated. In all cases, the buildings still stand and contain radioactive contamination above unrestricted levels. Some are closed and sealed but others have been converted to new, related facilities involving the use of radioactive materials.

A list of these facilities, and a detailed discussion of decommissioning steps taken at two of them appear in Reference 1. This report also contains a discussion of lessons learned from decommissioning experiences.

8.3 DECOMMISSIONING ALTERNATIVES

Once a MOX plant has reached the end of its useful operating life it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing all radioactive materials in excess of levels which would permit unrestricted use of the facility. Several alternatives are considered here as to their potential for satisfying this general requirement for decommissioning. The decommissioning alternatives considered and discussed here are DECON, SAFSTOR (custodial), and ENTOMB. Radiological effects and costs of each alternative are also discussed. After the radioactive inventory has been removed down to levels permitting unrestricted use of the facility and the contaminated equipment and structures decontaminated, demolition of the building would be left as an owner option. Therefore, demolition of the structures may or may not be included in either DECON or SAFSTOR.

The alternative used depends on such considerations as dose, cost, proposed use of the site, and desirability of terminating the license. A special consideration for decommissioning MOX plants is the half-lives of the radionuclides present in the facility. The radionuclides processed in a MOX plant are received from a reprocessing plant. Those radionuclides include plutonium and uranium and their decay products, but not fission products. There are several isotopes of these actinides, and the radioactivity of these isotopes is very high particularly that of the plutonium. These isotopes have such long half-lives that it is apparent that deferred decontamination for 10 or even 100 years would not result in reduced radiation doses to decommissioning personnel and, therefore, SAFSTOR would not appear to be a reasonable alternative without some other justification.

Safeguards will be required during each decommissioning alternative for protection of the public. Security is assumed to be similar to that needed during plant operation but on a smaller scale.

8.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivety in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down on removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as the 5 years estimated for decommissioning after the end of facility operation.

DECON is advantageous because it allows for termination of the NRC license shortly after cessation of facility operations and removes a radioactive site. DECON is advantageous if the site is required for other purposes, if the site is extremely valuable, or, if for some reason the site must be immediately released for unrestricted use. It is also advantegeous in that the facility operating staff is available to assist with decommissioning and that continued surveillance is not required.

The first step toward DECON is planning and preparation, which is initiated during the last 2 years of normal plant operation. During this time, detailed plans and procedures are prepared, a decommissioning staff is trained, safety and environmental impact reports are prepared if necessary, and effluent control systems modifications are started.

When the actual decommissioning work begins following shutdown, chemical decontamination of the wet process areas and physical cleanout of the dry process areas are started first. Physical decontamination of most plant areas proceeds next. Chemical decontamination involves flushing of internal surfaces of process piping and equipment, followed by spraying with chemical solutions the external surfaces of process equipment, piping, and internal surfaces of glove boxes.

Physical decontamination involves disassembly of equipment and enclosures and removal of the resulting materials. Physical decontamination also involves removal of contaminated parts of structural materials. These are packaged and transported offsite as waste, either as is or after chemical decontamination to remove bulk quantities of radionuclides. For DECON, disassembly and removal of equipment in some of the cleaner areas starts about 2 months after shutdown, and proceeds in parallel with chemical decontamination of other areas. The facility and service systems are removed as the last steps. At this point, the facility should be at or below acceptable levels of residual radioactivity and could be considered to be decommissioned. However, it may be desirable for non-radioactive reasons to remove the buildings, in which case the final phase would be demolition and restoration.

If demolition and restoration were used, all above grade portions of structures could be demolished using conventional methods such as explosives and impact balls. The site could then be graded and planted with vegetation to near pre-facility conditions.

Analyses of radiation exposures and costs for DECON are presented in Section 8.3.4.

8.3.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a MOX plant in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

Generally, the primary purpose of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However for the reasons given in Section 8.3 and as can be seen in Table 8.3-1 this is not necessarily the case for MOX plants. SAFSTOR could be advantageous in situations where there are overriding land use considerations. However, in addition to increased radiation exposure other disadvantages are that the licensee is required to maintain a material license and to meet its requirements at all times during safe storage thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantageous are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the deferred decontamination.

Chemical and physical decontamination activities in preparation for custodial safe storage are similar to those performed for DECON, except that for custodial safe storage, initial decontamination is generally done to the point that loose radioactivity is removed.

Preparations for the continuing care period of custodial safe storage involve deactivation and isolation of contaminated areas, sealing of contamination by adding durable seals or covering with paint, refurbishing the plant ventilation system, and installing improved alarm and protection systems for fire, intrusion, or malfunctioning equipment.

Continuing care activities may include operation of the facility ventilation system, routine inspection, corrective and preventive maintenance of the ventilation and other safety systems, environmental surveillance, and prevention of unneeded intrusion by man.

For the MOX facility, custodial safe storage is terminated eventually by deferred decontamination to levels permitting unrestricted use of the facility. For this action, activities are generally similar to those for DECON, with allowances for the prior decontamination efforts and retraining of new decommissioning staff.

Analyses of radiation exposures and costs for SAFSTOR are provided in Section 8.3.4.

8.3.3 ENTOMB

The ENTOMB alternative requires use of a structure to hold or confine the radioactivety until such time as it has decayed to levels which permit release of the facility for unrestricted use. ENTOMB would involve the encasement in concrete of heavily contaminated rooms within the reference MOX facility which would prevent the escape of radioactivity and prevent deliberate or inadvertant intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radionuclides present.

The MOX plant will still contain the 23 kg of plutonium estimated to remain in the process building following final inventory cleanout at shutdown, (see Section 8.1) including ^{239}Pu with a half-life of 24,390 years and the entombed structure would in effect become a new surface high level waste disposal site. This would be an undesirable situation in that it would be contributing to the problems associated with increased numbers of high level waste disposal sites. Moreover, the entombed structure would require surveillance in perpetuity which is well beyond the time that the required institutional control could be expected to be effective (approximately 100 years is considered to be consistent with recommended EPA policy on institutional control reliance for radioactivity confinemen. Although the ENTOMB option does not appear viable for the reasons given, it will be discussed for comparative perspective with the other options.

8.3.4 Summary of Radiation Safety and Decommissioning Costs

Each of the decommissioning alternatives has associated with it unavoidable radiation exposures, accident potential, and costs. As is seen from Table 8.3-1 none of these is appreciably reduced with time. This conclusion might change if technologies improve the reduction of accidental releases of radioactivity or the cost-efficiency of decontaminating the equipment.

8.3.4.1 Radiation Safety

Radiation safety for MOX plant decommissioning is discussed in detail in Reference 1. Dose calculations were based on maximum releases of radioactivity to maximize the consequences and thus present worst-case evaluations.

Occupational radiation exposure of workers performing the decommissioning activities results from external exposure to surface contamination for reasons similar to that discussed for PWRs in Section 4.3.1. Dose calculations are based on the estimated radiation levels in various areas of the plant and the estimated labor requirements for decommissioning each of those areas. Many of the radionuclides remaining in a MOX plant after shutdown have long half-lives. Generally preparation for safe storage does not involve extensive decontamination of these radionuclides. Because the half-lives of these radionuclides is long compared to the time that the facility might be held in safe storage awaiting deferred decontamination, the occupational radiation exposures will not decrease as a result of using the SAFSTOR alternative. There will be a shift in nuclide content from ^{241}Pu to ^{241}Am while a plant is in continuing care, but this shift will be insignificant. In calculating the total doses received, there are additional exposures incurred under the custodial safe storage mode that must be considered. These are shown in Table 8.3-1, which is a summary of the radiation exposures that may result from each of the decommissioning alternatives. It is to be noted again that the reference MOX plant for which the calculations were made is a small MOX plant.

TABLE 8.3-1. Summary of Radiation Safety Analyses for Routine Decommissioning of the Reference MOX Plant (man-rem)(a)

		SAFSTOR		
Occupational Exposure	DECON	10 Years	30 Years	ENTOMB
Preparation	NA	23	23	9.4
Continuing Care	NA	64	206	neg.
Decontamination(b)	70	70	70	NA
Transportation	6.4	8	8	0.6
Totals	76	165	307	10
Public Exposure (50-year dose commitment to critical organ)				
Preparation	NA	0.1	0.1	0.10
Continuing Care	NA	0.05	0.1	neg.
Decontamination(b)	2.2	2.2	2.2	NA
Transportation	1.5	1.9	1.9	0.15
Totals	3.7	4.3	4.3	0.25

(a) Adapted from Reference 1.

(b) For SAFSTOR, this is deferred decontamination.

The dominant radiation exposure pathway to members of the public during decommissioning operations is inhalation of airborne radionuclides for reasons similar to those discussed for PWRs in section 4.3.1. Emissions may result from either routine decommissioning activities or from potential accidental releases. Total estimated public exposures during routine decommissioning activities are small, as shown in Table 8.3-1.

A wide range of possible accidents that would result in released radioactivity is postulated. The largest releases are from failure of HEPA filters, cutting of contaminated metal, and explosion and/or fire in the ion exchange resins. These would result in the same quantities of release and radiation doses and have the same probabilities of occurrence with either decontamination alternative. A summary of the estimated doses to the public from accidents is shown in Table 8.3-2. The major postulated accident is the release of contaminated dust from an exhaust duct by failure of a HEPA filter. Radiation doses to the public resulting from accidents are low enough to be insignificant. Even with the failure of a HEPA filter which, as stated above, would result in a major accidental release, the public would be partially protected by the other filters in the system.

Radioactive waste materials are packaged and shipped offsite for burial during decommissioning of the reference MOX facility. These wastes include transuranic (TRU) contaminated wastes(a) that are shipped to a federal repository (deep geologic disposal) assumed to be located at 2,400 km (1,500 mi) from the plant site, and non-TRU wastes(b) that are shipped to a commercial shallow-land burial facility located about 800 km (500 mi)

(a) TRU wastes are assumed to be those contaminated with alpha radioactivity from transuranic materials at a level of 10 or more nCi/g of waste.

(b) Non-TRU wastes are assumed to have transuranic alpha radioactivity of less 10 nCi/g of waste.

TABLE 8.3-2. Summary of Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During Decommissioning Activities[a]

Incident	Release to Atmosphere (μCi)	First-Year Dose, mrem		Fifty-Year Dose Commitment, mrem		Expected Frequency of Occurrence[b]
		Bone	Lung	Bone	Lung	
Loss of Intermediate-Stage HEPA Filter After Exhaust Duct Decontamination	1.0×10^{4}	5.2	32	1.1×10^{2}	78	High
Inadvertent Cutting of Undecontaminated Metal	1.6×10^{2}	8.5×10^{-3}	5.0	1.8	1.3	High
Explosion and/or Fire of Ion Exchange Resin	83	7.0×10^{-2}	6.6×10^{-2}	2.5	7.0×10^{-2}	Medium
Inadvertent Dumping of Contaminated Solid Wastes:						
Abraded Firebrick	14	7.4×10^{-4}	4.4×10^{-2}	1.5	1.1	High
Concrete Dust	1.4	7.4×10^{-5}	4.4×10^{-3}	1.5×10^{-2}	1.1×10^{-2}	High
Condensed Metal Vapor	7.0×10^{-2}	3.8×10^{-6}	2.2×10^{-4}	7.9×10^{-4}	5.7×10^{-4}	High
Loss of Local Airborne Contamination Control/Loss of Vacuum Filter	3.5	1.9×10^{-4}	1.1×10^{-2}	3.8×10^{-2}	2.8×10^{-2}	High
Temporary Loss of Services: Electricity (Normal and Emergency)	1.4	7.4×10^{-5}	4.4×10^{-3}	1.5×10^{-2}	1.1×10^{-2}	Medium
Liquid Leak:						
Chemical Decontamination	16	1.4×10^{-2}	4.8	1.3×10^{-2}	1.4×10^{-2}	High
Electropolishing	2.8×10^{-2}	5.4×10^{-6}	5.1×10^{-6}	1.9×10^{-4}	5.1×10^{-6}	Medium
Fire Involving Contaminated Clothing or Combustible Waste	0.11	9.6×10^{-5}	9.2×10^{-5}	3.4×10^{-3}	9.2×10^{-5}	Medium
Explosion of Hydrogen During Electropolishing	7.1×10^{-3}	5.9×10^{-6}	5.5×10^{-6}	2.1×10^{-4}	5.9×10^{-6}	High
Man Intrusion	(c)	3.5×10^{6}	2.1×10^{8}	7.0×10^{8}	5.2×10^{8}	Low

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(a) This table is a summary of Table 11.2-3 in reference 1. It presents the highest dose from each of the decommissioning alternatives.

(b) Frequency of Occurrences: High $>1.0 \times 10^{-2}$ to 1.0×10^{-5}; Low $<1.0 \times 10^{-5}$ per year.

(c) This accident is for the ENTOMB alternative only and is postulated to be a deliberate but ignorant intrusion by man into the facility after knowledge of the facility is lost after a period of several hundred years. The case postulated assumes a 40-hour exposure to an average air concentration of 290 μCi/m³ of mixed oxides containing plutonium.

from the site. All wastes are assumed to be shipped by truck. To minimize the risk that radioactive shipments pose to the public and to transportation workers, federal and state regulations prescribe the containers, contents, packaging and handling, and burial requirements.

The dominant radiation exposure pathway to transport workers and the public during transportation of radioactive wastes is external exposure for reasons similar to those discussed for PWRs in Section 4.3.1. The external dose for routine transportation operations for all truck shipments, both high- and low-level wastes, from DECON is conservatively estimated to be about 6.4 man-rem to transport workers and 1.5 man-rem to the general public. For SAFSTOR (custodial) the radiation dose is estimated to be 8 man-rem to handling and transportation workers and 1.9 man-rem to the public. These doses are based on regulations of the Department of Transportation governing radiation levels in shipments of radioactive materials and on estimates the distances of travel and lengths of time of exposure that workers and the public might expect. These doses are summarized in Table 8.3-1.

The severity of accidents that may occur during transportation of radioactive waste depends on a number of factors, such as speed, kind of accident, and accident locations. Regardless of the decommissioning alternative, the same total amount of radioactive material will be transported. Thus, the possible release of radioactivity will be dependent on frequency and kind of accidents, as shown in Table 8.3-3.

TABLE 8.3-3. Estimated Frequencies, Radioactivity Releases and Doses for Selected Truck Transport Accidents

Severity of Accident (in Closed Van)	Frequency of Accidents per Facility: DECON	Frequency of Accidents per Facility: SAFSTOR	Release of Radioactivity[(b)] Ci	Radiation Dose for Maximum Exposed Individual (rem): 1st Year Bone	1st Year Lung	50 Year Dose Committment Bone	50 Year Dose Committment Lung
Minor	7.4×10^{-2}	9.9×10^{-2}	No Release	-	-	-	-
Moderate	1.8×10^{-2}	2.4×10^{-2}	1×10^{-4}	5.8×10^{-3}	2.6×10^{-2}	2.4×10^{-1}	6.5×10^{-2}
Severe	4.7×10^{-4}	6.3×10^{-4}	1×10^{-2}	6.8×10^{-1}	2.6	2.4	6.5

(a) Table adapted from NUREG/CR-0129, Table 11.4.3.

(b) Assumes a shipping inventory of 100 Ci of dispersable radioactive material.

8.3.4.2 Decommissioning Costs

This discussion of the decommissioning costs is based on information in NUREG/CR-0129.(1) Table 8.3-4 summarizes the estimated costs in 1978 dollars for the decommissioning alternatives analyzed in this report. All cost estimates include an added 25% for contingencies.

For DECON, the decommissioning costs are estimated to be $[illegible].6 million. For custodial SAFSTOR the total decommissioning cost is estimated to be $16.3 million and $28 million for 10-year SAFSTOR and 30-year SAFSTOR, respectively. These SAFSTOR costs include $3.5 million for preparation for safe storage, $0.54 million per year for continuing care, and $7.3 million for deferred decontamination. A present value analysis of decommissioning costs indicates a disincentive to defer decontamination for the reference case indicated, primarily because of the high cost of continuing care relative to DECON costs and the high cost of deferred decontamination due to the long half-lives of the radionuclides involved.

TABLE 8.3-4. Summary of Estimated Costs for Decommissioning the Reference Small MOX Fuel Fabrication Plant

	Estimated Costs in Million of 1978 Dollars			
		SAFSTOR (Custodial)		
Item	DECON	10 Years	30 Years	ENTOMB
Initial Decommissioning[a]	7.7	3.5	3.5	2.4
Continuing Care	NA	5.4	17.4	NA[b]
Deferred Decontamination[a]	NA	7.3	7.3	NA
Building Demolition and Site Restoration (optional)	0.1	0.1	0.1	NA
Onsite Burial	NA	NA	NA	0.4
Total Costs (Rounded)	7.8	16.3	28.3	2.8

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[a] Costs are based on ten shifts/week for most of the decommissioning. Decommissioning on a 24-hour/day basis would reduce costs and time requirements.

[b] Annual long-term care costs are estimated at $10,000.

For ENTOMB, the decommissioning costs are estimated to be $2.8 million. Long term care costs of an entombed structure will add an estimated $10,000 per year for tens of thousands of years.

As noted in Reference 1, labor costs are 66 to 75% of the total costs for the DECON and SAFSTOR alternatives and about 57% for ENTOMB. Thus, there is considerable incentive to institute plans or techniques that could reduce labor costs, such as working around the clock for the total decommissioning activities to reduce support labor and license and miscellaneous costs. The deferral of decontamination requires additional costs to refurbish auxiliary facilities, to reinstitute a trained decommissioning organization, and to provide a new safety analysis and application for amended license.

Cost of management of the wastes from decontamination amounts to less than 10% of the total costs. Thus, there is a modest economic incentive to reduce these costs. A potentially major economic factor favoring DECON is the value of the land or facility when released for productive uses. A facility in safe storage will provide economic return only as a tax write-off during the years before deferred decontamination, while a facility and land that have unrestricted use can be put to productive uses.

With the exceptions of the possible use of the process building and economic considerations, there is little or no advantage to either decommissioning alternative over the other regarding short-term and long-term uses. Once the facility has been prepared for custodial safe storage, the only area of concern for exposure to radionuclides is inside the exclusion area and, depending on the perceived potential accident risks, the rest of the property may be released for unrestricted use. In the reference facility and site, the building is sited in an exclusion area of 1.2 hectares (3 acres). This exclusion area represents about 0.25% of the total site area of 470 hectares (1160 acres).

However, in view of the fact that SAFSTOR offers no advantages from reduced radioactivity (in fact, a small increase in potential hazard from a buildup of ^{241}Am), it appears that DECON would be the more acceptable of these two decommissioning alternatives for MOX plants.

8.4 ENVIRONMENTAL CONSEQUENCES

The decommissioning of a MOX plant has few negative environmental consequences. As was defined in Section 2.3, the decommissioning of any nuclear facility involves the removal of radioactive material to levels which permit release of the facility for unrestricted use. The decommissioning alternative to be chosen depends to a large extent on the radiation dose, cost evaluations, desired future use of the site, desirability of terminating the license and the time period. The summaries of radiation safety and decommissioning costs are given in Section 8.3.4.

Demolition of remaining buildings (assuming prior decontamination to a level permitting unrestricted use of the MOX plant) is an optional owner and/or local government choice. Its major environmental impact on the surrounding population will be the resulting increase in noise level within the immediate vicinity of the plant (about 1 mile), primarily because of the use of explosives. However, most of the noise will be generated within the process building and will be muffled by the building until the final removal of the building shell.

8.4.1 Waste

A major environmental consequence of decommissioning is the commitment of land area to the disposal of radioactive waste. PNL made the estimates shown in Table 8.4-1 of the waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. The volume for ENTOMB does not include the volume of the entombing structure or the wastes entombed within it. The entombing structure is effectively a new shallow high level radioactive waste burial ground, separate and distinct from the ones in which the wastes in Table 8.4-1 are buried.

TABLE 8.4-1 Burial Volume of Radioactive Waste and Rubble Resulting from Decommissioning a Reference MOX Plant(m^3)

		SAFSTOR (Custodial)		ENTOMB
Disposition of Waste	DECON	10 Years	30 Years	
Deep Geologic Disposal	164	205[a]	205[a]	21
Shallow Land Burial	267	267	267	5
Total	431	472	472	26[b]

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[a] Includes 52 m^3 of waste from preparation for safe storage.

[b] Does not include volume of entombing structure or entombed waste.

If shallow land burial of radioactive waste in standard trenches is assumed, then a burial volume of 267 m^3 of radioactive waste can be accommodated in less than 0.02 acres. An additional 164 m^3 would be required in a high level waste repository for DECON. An additional 52 m^3 of high level waste disposal space would be required for SAFSTOR at an additional cost of approximately $1.4 million.

These land use requirements for waste disposal are not large in comparison with the approximately 1160 acres used as the site of the reference MOX plant which could now be returned to unrestricted use.

An additional effect of decommissioning is that the decontamination of a MOX plant will require the use of expendable tools and material that will be discarded as low-level waste at an estimated cost of about $1.1 million.

8.4.2 Nonradiological Safety

Two potential nonradiological safety considerations are recognized. These are releases of chemicals used to decontaminate the plant and accidents in transporting materials to and from the plant.

Chemicals used in decontamination are detergents, oxidizing agents (acids), reducing agents, chelating agents, acids, caustics, and electropolishing solutions. Fumes from these chemicals will not be a safety hazard to workers provided there are adequate precautions and ventilation. Possibly the greatest potential for gaseous emissions is from the electropolishing process. Hydrogen and oxygen will be evolved in amounts that are proportional to the applied current and the surface area. For example, if a current of 10,000 A is applied to an area of 6 m^2 at an electropolishing station, hydrogen gas will be evolved at the rate of 4.5 m^3 per minute and oxygen at half that rate, for a total of 6.8 m^3 per minute. At this rate of release, these gases will entrain 10 mg of liquid electrolyte per m^3 of gas. The air filtering system operating for the removal of radionuclides will also remove this entrained liquid. Adequate ventilation will keep a fire or explosion from developing by preventing the hydrogen concentration in the air from building up to exceed the lower flammability level of 4.1%. This consideration will be very important when electropolishing a closed container such as a tank.(1)

Shipment of materials in and out of the plant will inherently have the same risk of accidents as any other shipping activities. Since transport is assumed to be by truck, the probability of accidents can be estimated from highway travel statistics. Assuming 630 round trips of 1600 km (1000 miles) to a shallow land burial site and 32 round trips of 4800 km (3000 miles) to a deep geologic burial site, there may be expected about 0.61 injuries and 0.036 fatalities per facility.(1)

8.4.3 Socio-economic Effects

An immediately felt non-decommissioning effect of closing a MOX plant will be the loss of employment. A plant that has not been operating (as is the case with some of the existing plants) will require that a number of people be hired and trained, thus providing short-term employment (1 to 5 years). If decommissioning follows immediately after shutdown, some of the operating personnel will be used in the decommissioning work, thus providing a reduced level of employment for a short time. In the case of DECON, the staff size will remain at about a constant level until the decontamination activities near completion nearly 3 years after shutdown. In the case of custodial SAFSTOR, the staff will decrease as soon as initial chemical decontamination is completed. Throughout the period of continuing care, only maintenance, monitoring, and security personnel will be required. At the end of the continuing care period, the staff size will again increase to accomplish the final decontamination. Unless decontamination is performed by a contractor with a trained staff, a decontamination crew will have to be recruited and trained before this work begins. Changes in employment levels will not occur suddenly but will happen over the decommissioning period regardless of the decommissioning alternative. The custodial SAFSTOR alternative will require a small staff throughout the continuing care period, but this will be a small part of any local economy.

One possible benefit to the community will result from the removal of restrictions on the use of the land, which may happen if the facility is not used for other nuclear activities.

8.4.4 Noise and Aesthetics

One environmental effect will result from noise. Noise levels during decontamination will increase over operation levels because of the physical removal of concrete surfaces. Because these activities will be inside the buildings and because the buildings are some distance from the site boundary, these noises will not likely be heard offsite.

Aesthetic effects will not likely be a result of the decommissioning process per se, but will rather depend on the final disposition of the building and site. Removal of the MOX building will allow the site to be returned to its preconstruction state or be used for any other purpose. A building that is being held in continuing care may not require limitations on the use of the remainder of the site. The ENTOMB alternative will result in a large mound of earth whose blending into its surroundings will depend largely on the local terrain. This mound could be quite conspicuous in a flat area. In addition, the earthen fill must be taken from some borrow area and careful planning will be required to prevent this from creating another set of aesthetic problems. Thus, the aesthetic impact of ENTOMB is potentially greater than that for one of the other decontamination alternatives.

8.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives as discussed here apply to a small MOX plant. Economics and radiation exposures may change somewhat for a facility with different characteristics.

The alternatives considered viable are DECON and custodial SAFSTOR. The differences between these alternatives are very small in matters of environment, ecology, and aesthetics. The major differences occur in occupational radiation exposure and decommissioning costs. Due to the long-lived nature of the radionuclides present in the MOX plant, doses and costs are not reduced even when decontamination is deferred for 30 years, as can be seen from Tables 8.3-1 and 8.3-4. Since the cost and doses of continuing care is a major item and continues to increase with increasing safe storage time, the doses and costs associated with the complete SAFSTOR process exceed those for DECON. Thus, DECON would seem to be the most advantageous alternative.

Over the short-term, ENTOMB appears to offer some economic advantage in that initial costs are lower than for other alternatives. This advantage disappears, however, over the long-term because of the need to maintain surveillance of the site in perpetuity. Major societal concerns of this alternative include the problems associated with increased numbers of nuclear waste sites, holding long-lived hazardous materials near man's environment, and maintaining financial responsibility. All of these concerns combine to make ENTOMB an unacceptable alternative.

REFERENCES

1. C. E. Jenkins, E. S. Murphy and K. J. Schneider, Technology, Safety, and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant, NUREG/CR-0129, Vol. 1 and 2, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission. February 1979. Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

9.0 LOW-LEVEL-WASTE BURIAL GROUND

Development of an EIS in support of regulations concerning the disposal of low-level waste along with accompanying regulatory activity for 10 CFR Part 61 is currently in progress. Additional details are given in the Federal Register Notice, 45 Fed. Reg. 13104 (1980).

10. URANIUM HEXAFLUORIDE CONVERSION PLANT

The function of a uranium hexafluoride (UF_6) conversion plant is to convert uranium concentrates, received from various uranium mills, to the purified uranium hexafluoride that is used as the feed material for the gaseous diffusion enrichment of ^{235}U. Currently there are five conversion plants in operation in the United States. Their names and locations are:

Allied Chemical	Metropolis, Illinois
Kerr-McGee	Sequayah County, Oklahoma
Fernald DOE	Cincinnati, Ohio
Paducah, DOE	Paducah, Kentucky
Portsmouth, DOE[a]	Portsmouth, Ohio

Three other plants have been shut down: the Mallinckrodt Chemical Company Plant at Welden Springs, Missouri, the NUMEC Plant at Apollo, Pennsylvania, and the Oak Ridge Enrichment Plant.

The plant described here is a reference plant that is assumed to have processed 10,000 metric tons (MT) per year of natural uranium and to have been in operation for about 30 years. A detailed report on the decommissioning of a UF_6 plant, similar to those prepared for other facilities discussed in this EIS, is planned for issuance in fiscal year 1982. The reference plant discussed here is based on the latest technology. For the plants listed above, currently operating plant processes vary from the reference plant in the type of equipment that is being used to perform the same process steps. However, from a decommissioning standpoint, the differences in the amount and size of equipment for various plant processes and the reference plant are small. Therefore, this decommissioning description is considered representative.

10.1 URANIUM HEXAFLUORIDE CONVERSION PLANT DESCRIPTION

10.1.1 Plant and Process Description(1,2)

The reference UF_6 plant is assumed to occupy about 30.4 hectares (75 acres) within the generic site described in Section 3. The plant consists of three buildings containing approximately 120,000 ft^2 of floor area. The buildings are of normal industrial construction, with heavy concrete floors to support equipment. In addition, there are a series of retention ponds for sanitary waste and process raffinates. The plant is designed to receive U_3O_8 or yellowcake in 208-liter (55-gallon) drums from various uranium mills located in the western United States and to convert the feed stock to uranium hexafluoride (UF_6). Two processes are in use today, which differ only in the method of purification. The major steps in either process are:

1. pre-process handling, weighing, sampling, and storage
2. conversion of the U_3O_8 or yellowcake to uranium trioxide (UO_3) by roasting

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[a] The large hexafluoride conversion plant was put into safe storage in the 1961-62 period. It has since been converted to another use. There is currently a small hexafluoride plant for converting returned and reclaimed uranium compounds to feed for the cascade enrichment plant.

3. reduction of the UO_3 to UO_2 with hydrogen
4. hydrofluorination of the UO_2 to UF_4 with hydrogen fluoride
5. fluorination of the UF_4 to UF_6 with elemental fluorine
6. storage of the purified UF_6 in shipping cylinders.

The purification step is added either at the beginning using a solvent extraction process or at the end by fractional distillation of the UF_6. The use of the solvent extraction purification step (the wet process) results in the radioactive uranium daughters (^{230}Th and ^{226}Ra) and impurities being left in the solvent extraction raffinate and being disposed of in a shallow-land burial ground or returned to the mill for disposal with the tailings (see Figure 10.1-1). The dry process, on the other hand, removes the impurities from the UF_6 product stream by fractional distillation and incorporates them with other waste products for disposal as solid waste in a shallow-land burial ground (see Figure 10.1-2). All gaseous effluent streams are filtered, and those containing fluorine compounds are scrubbed with potassium or calcium hydroxide solution.

The plant equipment, fabricated mostly of monel, is mainly a series of fluidized bed chemical reactors with intermediate vessels, such as storage bins, air classifiers, product filters, cold traps, and air effluent purification systems. The plant facility has pond areas for liquid effluents(3) and a burial area for disposal of defunct equipment.

The purified UF_6 is placed in cylinders for storage and future shipment to one of the Department of Energy's enrichment plants.

10.1.2 Estimates of Radioactivity Levels at UF_6 Plant Shutdown

The reference UF_6 plant processes 10,000 metric tons of natural uranium per year in the form of ore concentrate (yellowcake) produced by domestic uranium mills. The feed to the reference UF_6 plant is assumed to be a composite product of uranium, produced 85% from acid leach and 15% from alkaline leach, which has aged at least six months in sealed drums after milling. The radionuclides of primary concern are natural uranium, ^{226}Ra, ^{230}Th, ^{234}Th, ^{234m}Pa, and ^{222}Rn. The daughter products of radon are not listed as radionuclides of primary concern either because they have half-lives of less than 2 hours and do not accumulate in the bioenvironment (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{210}Po) or because they individually contribute less than 0.02% of the total relative hazard (^{210}Pb, ^{210}Bi, and ^{210}Po).(2) Analysis of the plant feed at the Allied Chemical Plant at Metropolis, Illinois,(2) indicates that there are 2,800 picocuries of ^{230}Th and 200 picocuries of ^{226}Ra per gram of natural uranium. This amounts to 28 curies of ^{230}Th and 2 curies of ^{226}Ra entering the plant each year, the majority of which is recycled at the mills by wet processing or to low-level waste burial as solid waste during dry processing. Natural uranium is the most abundant radionuclide present. The predominant health and safety consideration is not radiological, but rather the effect that heavy metal (uranium) chemical toxicity has on the human kidney.

10.2 URANIUM HEXAFLUORIDE CONVERSION PLANT DECOMMISSIONING EXPERIENCE

DOE has terminated UF_6 conversion at the Oak Ridge Enrichment Plant and at the Mallinckrodt Chemical Company Plant at Welden Springs, Missouri. The Welden Springs Plant is currently undergoing decommissioning, and the knowledge gained from this experience will be useful in the planning and decommissioning of similar plants. The status of decommissioning of the Oak Ridge Plant is not known at this time.

10.3 DECOMMISSIONING ALTERNATIVES

Once a UF_6 plant has reached the end of its useful operating life, it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing of all radioactive materials

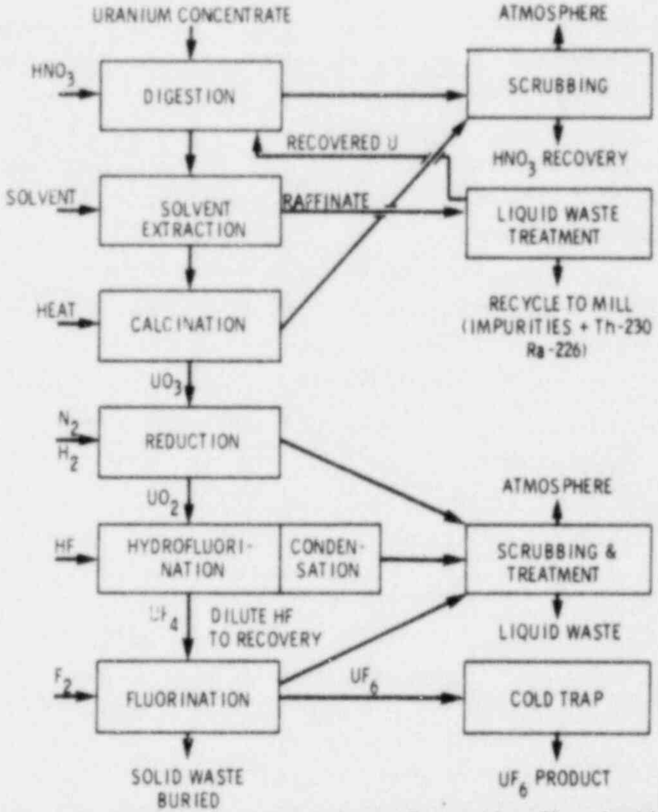

FIGURE 10.1-1. UF_6 Production - Wet Solvent Extraction Fluorination Process Simplified Block Flow Diagram

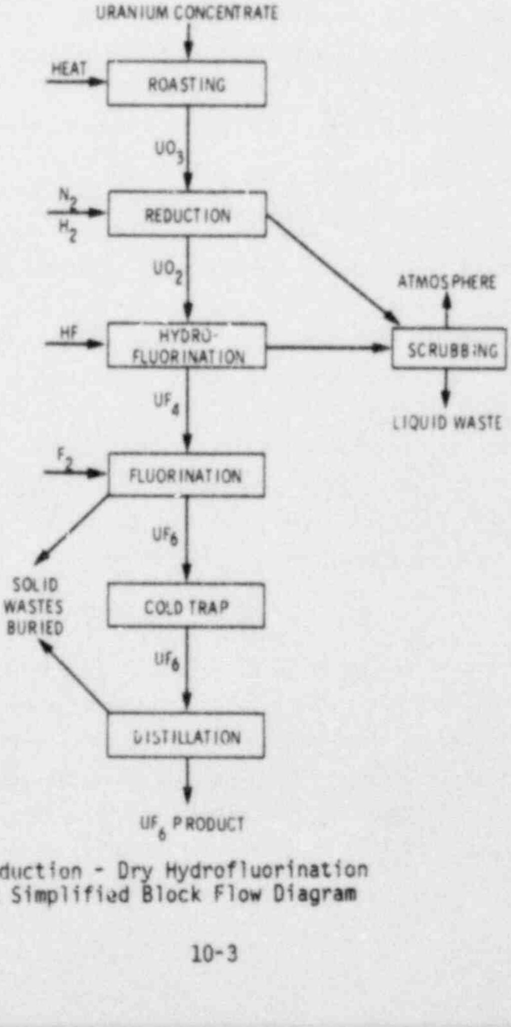

FIGURE 10.1-2. UF_6 Production - Dry Hydrofluorination Process Simplified Block Flow Diagram

in excess of levels which would permit unrestricted use of the facility. Several alternatives are considered here as to their potential for satisfying this general requirement for decommissioning. The decommissioning alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB.

The alternative used depends on such considerations as cost, dose, proposed use of the site and desirability of terminating the license. Special considerations involved in decommissioning the reference UF_6 plants include the following general assumptions:

1. natural uranium and its radioactive daughters are the only radioactive materials handled at the plant,

2. uranium spills that occur during the life of the plant, both inside and outside, are cleaned up immediately, and

3. safety reasons dictate that the maximum amount of uranium be removed from the plant prior to decommissioning.

Other considerations include the fact that decontamination of equipment is comparatively easy since most uranium found at the UF_6 conversion plant is quite soluble in nitric acid (HNO_3) and aluminum nitrate.(1) The cleanout of the plant following shutdown removes essentially all of the uranium. Decommissioning following this cleanout flush should be equivalent to the cleanup of any chemical processing plant, since all but trace amounts of uranium would have been removed. An extensive radiation survey of the buildings and equipment would pinpoint any contaminated areas and thus allow an estimate to be made of the time and money needed for decommissioning. This radiation survey may show that all of the buildings and equipment can be released for unrestricted use, although it is more probable that some are releasable and some need further decontamination. Because of the low specific activity of uranium, radiation exposures of the public and the workers are negligible and therefore are of little concern, the owner could choose the most economical alternative for decommissioning with NRC concurrence. The most practical choice of decommissioning alternatives based on economics, appears to be basically only one: DECON. However, the other options listed above are briefly discussed here.

10.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as the 1 year estimated for decommissioning after the end of facility operation.

DECON is advantageous because it allows for termination of the NRC license shortly after cessation of facility operations and removes a radioactive site. DECON is advantageous if the site is required for other purposes or if the site is extremely valuable. It is also advantageous in that the facility operating staff is available to assist with decommissioning and that continued surveillance is not required.

Because of the low radiation exposures from natural uranium, DECON could start at once following the final operational equipment flush and radiation survey. Salvageable equipment would be decontaminated as necessary by water or nitric acid flushing, hand scrubbing, or by vibratory or electropolishing techniques. Nonsalvageable hard-to-decontaminate equipment would be shipped to a low-level waste burial ground for disposal. The structures used to house the UF_6 process would be decontaminated as necessary and then demolished or used for another purpose at the discretion of the owner. The site would be surveyed and any contamination would be removed. All contaminated materials would be disposed of in a low-level waste burial ground.

The disassembly of the equipment would result in valves and piping being boxed for disposal. The process vessels, with the exception of a few large diameter (3 m, or 10 ft) tanks, are all of such size that they will fit into a van-type truck 7.3 m (24 ft) long. The larger vessels will be cut into pieces for disposal. The vessels would act as their own containers and have all openings bolted or welded closed. Trash would be stuffed into the vessels for disposal.

Ten percent of the concrete floor is assumed to be contaminated and 10 cm (4 in.) of the top of this surface is chipped away and disposed of as rubble. This estimate allows for a small amount of building materials that might need to be disposed of in a shallow-land burial site.

The removal of the uranium from the process equipment removes any significant radiation exposure to either the public or to the decommissioning worker. The radiation dose for the dismantling crew is expected to be less than for the initial cleaning. Average radiation dose rates in the plant during the initial cleaning are expected to be one or two orders of magnitude less than 2 mrem/hr, which is the radiation dose rate from bulk quantities of uranium. Thus, the decontamination of the plant, packaging of contaminated wastes, and transporting of this material to a low-level waste burial ground is estimated to result in negligible radiation exposure to the public or to the worker. (see Table 10.5-1)

Table 10.5-1 summarizes the estimated costs in 1978 dollars for the decommissioning alternative analyzed in this report. The DECON costs are estimated to be $2.3 million. These costs include costs for labor, equipment and materials, waste disposal and other expenses. All cost estimates include an added 25% for contigencies. A time period of about 1 year is estimated for DECON.

Once DECON is complete, i.e., once the facility is decontaminated to levels permitting release of the facility for unrestricted use, the radioactive materials license would be terminated and the owner would be free to dispose of the site as he wished.

10.3.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a UF_6 plant in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use deferred decontamination).

Generally, the primary purpose of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However for the reasons given in Section 10.3 and as can be seen in Table 10.5-1 this is not the case for UF_6 plants. SAFSTOR could be advantageous in situations where there are overriding facility reuse or land use considerations. However, disadvantages of SAFSTOR are that the licensee is required to maintain a material license and to meet its requirements at all times during safe storage thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantages are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the deferred decontamination.

Safe storage preparation is the same as the initial decontamination. The buildings and areas would be secured, but because of the small amount of radiation (less than 1 mrem/hr) and minimal danger to an intruder, only periodic surveillance would be necessary (twice per week). The length of the continuing care period would then be at the option of the owner. Continuing care would cost approximately $45,000 per year. A safe storage period of 10 years would result in total SAFSTOR costs of $2.8 million, which is larger than for DECON. This would take place with no increase or decrease in total radiation dose to the public or workers. Deferred decontamination could take place at any time, would require the same steps as DECON and would result in similar costs and doses as for DECON.

For the reasons discussed in Section 10.3 radiation dose to the public and workers would be negligible (see Table 10.5-1).

10.3.3 ENTOMB

ENTOMB of a UF_6 plant until its radioactivity has reached levels permitting release of the facility for unrestricted use requires its encasement in concrete to protect the public from radiation exposure. Because the radiation levels from the trace amount of natural uranium in the equipment and buildings are nearly zero and because the process buildings are not suitable for ENTOMB, this is a very expensive and unnecessary decommissioning alternative and is not considered a viable option.

10.3.4 Site Decommissioning

No site decommissioning other than a radiation survey is expected to be necessary since it is assumed that each spill will be cleaned up immediately. If failed equipment or other contaminated solids have been buried onsite, they will have to be removed to a low-level burial ground. However, the removal of onsite buried materials is expected to be a minor effort compared to the rest of the decommissioning.

10.4 ENVIRONMENTAL CONSEQUENCES

The environmental consequences of decommissioning a UF_6 conversion plant are small. The largest environmental impact is postulated to be the use of about 0.2 hectare (0.5 acre) of irretrievable land for shallow-land burial and the consumption of materials (gasoline, wood, metal tools, etc.) during the decommissioning activities. Decommissioning would make the 30.4 hectares (75 acres) of plant-site land available for unrestricted use. Reactivation of the site as another industrial endeavor would be advantageous to the local residents, about 100 of whom worked at the plant. The occupational and public radiation doses which are negligible, are discussed in Section 10.3. Discussion of costs are also included in Section 10.3.

10.4.1 Industrial Safety Consequences

The lost-time injuries and fatalities for the various decommissioning activities are given in Table 10.4-1.

TABLE 10.4-1. Estimated Occupational Lost-Time Injuries and Fatalities for Various Decommissioning Activities

		Estimated Numbers of Accidents per Activity	
Activity	Man-Hours Exposure	Lost-Time Injuries	Fatalities
Decontamination	99 000	0.393	0.003
Transportation	(60 800 km)	0.033	0.002
Total	---	0.426	0.005
Annual Continuing Care[(a)]	1 100	0.002	0.00003

(a)These lost-time injuries and fatalities should be added to the total above for each year of continuing care.

10.4.2 Waste Disposal

The volume of low-level waste to be disposed of is estimated on the basis that all process equipment is discarded. The volume estimated, 570 m^3, is considered to be a maximum that requires about 0.2 hectare (0.5 acre) of a shallow-land burial site. Any equipment that can be reused or released for salvage will reduce the volume sent to burial. The land used for burial is considered irretrievable. These land use requirements for waste disposal are not large in comparison with the approximately 1160 acres used as the site of the reference UF_6 plant which could now be returned to unrestricted use.

10.4.3 Additional Effects of Decommissioning

The socio-economic impacts are mainly from the shutdown (not decommissioning) of the facility and associated loss of about 100 jobs. Since the main attributes of an industrial site are still available, it would be in the best interests of the local communities to establish a new industry that would supply jobs and money through taxes. On the basis of economics, this use of the site would probably be preferred to returning it to its original condition.

10.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

Table 10.5-1 presents a summary of the decommissioning alternatives discussed in this section. The choice of an alternative generally depends on such considerations as dose, cost, proposed use of the site, and desirability of terminating the license. As discussed in Section 10.3.4, ENTOMB is not considered a viable option and is not listed in Table 10.5-1. Of the two remaining alternatives, DECON and SAFSTOR, DECON appears to be the more advantageous option. This is because the radiation doses are negligible for either alternative, while DECON has lower costs and results in release of the facility for unrestricted use in a fairly short time period.

TABLE 10.5-1. Summary of Decommissioning Alternatives

		SAFSTOR		
	DECON	10 Years	30 Years	100 Years
Total Cost (millions of constant 1978 dollars)	2.3	2.75	3.65	6.80
Public and Occupational Radiation Dose (man-rem)	neg[a]	neg	neg	neg
Potential Industrial Accidents - Injuries	0.426	0.446	0.486	0.626
Fatalities	0.005	0.0053	0.0059	0.008
Manpower Expenditures (cumulative man-years)	49	55	66	106
Land Area Committed (acres)	0	75[b]	75[b]	75[b]

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[a] Negligible

[b] Part of the site might be decontaminated, surveyed, and released for unrestricted use while the facility is put in safe storage, if desired.

REFERENCES

1. C. D. Harrington and A. E. Ruehle, Uranium Production Technology, D. Van Hostrand Company, Inc., Princeton, NJ, 1959.

2. M. B. Sears, R. E. Blanco et al., Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle Conversion of Yellow Cake to Uranium Hexafluoride. Part I: The Fluorination Fractionation Process, ORNL/NUREG/TM7, Oak Ridge National Laboratory, Oak Ridge, September 1977.

3. Regulatory Guide 3.13, Guide for Acceptable Waste Storage Methods at UF_6 Production Plants, U.S. NRC, October 1973.

11.0 URANIUM FUEL FABRICATION PLANT

A uranium fuel fabrication plant (U-fab plant) is a facility in which enriched uranium, received as uranium hexafluoride (UF_6), is converted to UO_2 and formed into fuel pellets that are inserted into fuel rods. These fuel rods are, in turn, assembled into fuel bundles. There are two kinds of U-fab plants: high-level enriched U-fab plants which produce fuel for reactors that power naval vessels and for reactors that serve other special purposes, and low-level enriched U-fab plants which produce fuel for commercial nuclear power reactors that generate electricity. Plants that fabricate fuel for the U.S. Navy are outside the scope of this EIS, but their decommissioning impact would be similar to the decommissioning of low-level enriched U-fab plants.

Some low-level enriched U-fab plants perform the whole operation, i.e., they receive UF_6 and produce fuel bundles. Other facilities operate in two stages, i.e., one plant receives UF_6 and produces UO_2 powder or pellets, and a second plant assembles the fuel rods and bundles. The reference plant for this study performs the whole operation.

This section presents an assessment of the environmental effects that may be expected from the decommissioning of such a facility. This section is based primarily on information from a study(1) of the decommissioning of a uranium fuel fabrication plant. In this study PNL selected the General Electric Plant located at Wilmington, North Carolina as the reference U-fab plant and assumed it to be located at the generic site. The generic site is described in Section 3.1. As part of this study, PNL developed information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life.

11.1 U-FAB PLANT DESCRIPTION

The reference U-fab plant is assumed to have operated for 40 years, processing an average of 1000 MT of uranium per year. Production consists of three general kinds of activities: conversion of slightly enriched UF_6 to UO_2; mechanical production of fuel pellets and assembly of fuel rods and bundles; and recovery of uranium from scrap, wastes, and off-standard pellets.

Conversion of UF_6, as received from an enrichment facility, to UO_2 is accomplished by either a chemical or a direct process. In the chemical process, the UF_6 is first hydrolyzed to UO_2F_2 and ammonium hydroxide is added to precipitate the uranium as ammonium diuranate (ADU). Then the ADU is reduced and calcined to produce UO_2 powder. In the direct process, conversion reactors convert UF_6 directly to U_3O_8, which is then reduced to UO_2.

In the production of pellets, the UO_2 is pulverized and compacted to granules of a desired density. The granules are pressed into pellets which are sintered at high temperature in a reducing atmosphere. The pellets are then ground to proper size and loaded into Zircaloy or stainless steel tubes which are dried, evacuated, filled with helium, and welded closed. The tubes (now called fuel rods) are tested for leaks, assembled into fuel bundles, inspected and stored for shipment.

The building is a two-story, windowless structure of concrete and steel. Interior walls, typically of concrete block, divide the building into discrete operations areas that house each of the production steps. When the plant is shut down and the final inventory cleanout has been performed, it is anticipated that there will be a total of about 270 kg of unrecovered uranium remaining in the plant. Of this amount, approximately 150 kg is in the equipment and 120 kg is in the ventilation system. This uranium has enrichments that range from 2% to less than 5% ^{235}U. CaF_2 is a waste product that is produced by treating the fluoride wastes with $Ca(OH)_2$. The CaF_2 is stored in waste ponds. Those CaF_2 waste ponds will contain some enriched uranium and will therefore require some decommissioning activity. Although CaF_2 has low solubility, the toxicity of inorganic fluorides in general suggests that these wastes may be a biological hazard.(2)

11.2 U-FAB PLANT DECOMMISSIONING EXPERIENCE

Several U-fab plants have ceased operation and are in various stages of decommissioning. At some facilities a high-level enriched U-fab operation has been shut down, leaving a low-level enriched U-fab operation still in production. Examples are a Babcock and Wilcox Plant at Apollo, Pennsylvania, and a Combustion Engineering Plant at Hematite, Missouri. At the Combustion Engineering Plant, there has been a partial cleanup, but at neither plant has the facility been completely decommissioned. Babcock and Wilcox also has a high-level enriched plant at Leechburg, Pennsylvania, that has been shut down and partially decommissioned. Some equipment has been removed but the ventilation system is still intact. United Nuclear closed a high-level enriched U-fab plant at New Haven, Connecticut, several years ago and U.S. Nuclear Corporation decommissioned a high-level enriched U-fab test and research facility at Oak Ridge, Tennessee.

Among the low-level enriched U-fab plants, two facilities which have been shut down are examples of decommissioning experience. A Kerr-McGee Plant at Crescent, Oklahoma, has been partly decommissioned. The plant is still intact, but the waste ponds have been cleaned up. This waste was loaded into drums and shipped to a burial ground.

Perhaps the best experience in decommissioning a low-level enriched U-fab plant was with a General Electric U-fab Plant in San Jose, California. At shutdown, the area was cleaned to administrative control levels not exceeding 1000 dpm/100 cm^2. Decommissioning was accomplished by dismantling and removing all of the process equipment and ventilation system and cleaning the building. Pipes, lighting fixtures, etc., were cleaned; fluorescent tubes were replaced; ceilings, walls, pipes, and lighting fixtures were damp-wiped; baseboard moldings and tile floors were removed; and concrete floors were vacuumed and mopped. Pump basins that had been formed by constructing concrete berms were cleaned up by removing the berms and wet grinding hot spots. The decommissioning effort was more extensive than should have normally been necessary, because on one occasion an accident occurred that released a large amount of UF_6 inside the plant. This accident contaminated not only all the building and fixture surfaces in the production areas but also the otherwise clean areas, such as offices.

11.3 DECOMMISSIONING ALTERNATIVES

Once a U-fab plant has reached the end of its useful operating life it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing of all radioactive materials in excess of levels which would permit unrestricted use of the facility. Several alternatives are considered here as to their potential for satisfying this general requirement for decommissioning. The decommissioning alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB. The alternative used depends on such considerations as cost, dose, proposed use of the site and desirability of terminating the license.

Most of the residual radioactivity in a U-fab plant following shutdown is surface contamination,(3) although concrete in some areas of the plant may be contaminated to a shallow depth. It is assumed that a complete radiological survey of the plant and its equipment will be made as a normal operational procedure at the time of shutdown and that nitrate wastes have been removed and reprocessed as a part of normal operations. Thus, preparing the facility for unrestricted use will involve removal of the equipment, decontamination of the building, removal of some concrete surfaces as indicated by the survey, disposal of chemical wastes, and disposal of the CaF_2 wastes in the lagoons.

Discussions of the decommissioning alternatives follow:

11.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedures. The end result is the release of the site and any remaining structures for unrestricted use as early as the 9 months estimated for decommissioning after the end of facility operation.

DECON is advantageous because it allows for termination of the NRC license shortly after cessation of facility operations and removes a radioactive site. DECON is advantageous if the site is required for other purposes or if the site is extremely valuable. It is also advantageous in that the facility operating staff is available to assist with decommissioning and that continued surveillance is not required.

DECON of a U-fab plant presents few problems. The equipment and ventilation systems are removed and the building surfaces are damp-wiped. The equipment and vents most highly contaminated will be in the calciner, press, hammer mill, blender, and grinder areas. Some of this equipment and the furnaces can be reclaimed by replacing the parts that were exposed to the uranium. While the same may apply to the vent systems, it is likely that much of this material will be discarded. The replaced and discarded material will be shipped to a low-level waste burial ground. In some parts of the building, particularly the chemical processing areas, there will be places, such as pump basins, where it will be necessary to remove concrete floor surfaces. This will be accomplished by grinding, chipping or spalling, with the removed concrete being sent to a low-level waste burial ground.

The major problem in decommissioning a U-fab plant may be with the waste ponds and other areas where the soil is contaminated. Wastes in the nitrate ponds will have been removed, shipped to another plant, and reprocessed; but the calcium fluoride waste may have to be removed a shipped to a low-level waste burial ground. It is also possible that the CaF_2 waste may be removed and reprocessed at another plant to recover uranium. The CaF_2 would then be disposed of by the new owner. The non-radioactive chemical wastes will be sent to a chemical waste burial ground.

Analyses of radiation exposure and costs for DECON are presented in Section 11.3.4.

11.3.2 SAFSTOR (Custodial)

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a U-fab plant in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

Generally, the primary purpose of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However for the reasons given in Section 11.3.4.1 and as can be seen in Table 11.3-1 this is not necessarily the case for U-fab plants. SAFSTOR could be advantageous in the event that a company wishes to discontinue the operation of a U-fab plant but has no immediate alternative use for the facility or the site. If this is the case it may be desirable to place the facility in custodial safe storage prior to deferred decontamination leading to release of the facility for unrestricted use. Custodial SAFSTOR for a UF_6 plant would require only minimal cleanup with continuing maintenance and security. The CaF_2 wastes may have to be sold and removed for reprocessing or removed to a permanent waste burial ground. The chemical wastes will be removed to a chemical waste disposal area.

TABLE 11.3-1 Summary of Radiation Safety Analyses for Routine Decommissioning of the Reference U-fab Plant (man-rem)[(a)]

		SAFSTOR	
Occupational Exposure	DECON	10 years	30 years
Preparation	NA	0.4	0.4
Continuing Care	NA	11	33
Decontamination[(b)]	16	16	16
Transportation	2.6	2.6	2.6
Totals	18.6	30	62
	(50 year dose commitment to the critical organ)		
Public Exposure			
Preparation	NA	0.06	0.06
Continuing Care	NA	0.05	0.15
Decontamination[(b)]	0.06	0.06	0.06
Transportation	0.53	0.53	0.53
Totals	0.6	0.7	0.8

[(a)] Adapted from Reference 1

[(b)] For SAFSTOR, this is deferred decontamination

Another disadvantage of SAFSTOR, in addition to increased radiation exposure, is that the licensee is required to maintain a material license and to meet its requirements at all times during safe storage thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantages are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the deferred decontamination.

Over the short-term, custodial SAFSTOR might be temporarily expedient, but neither the cost of eventual decontamination nor the occupational radiation dose would be decreased by delaying decontamination due to the long half-lives of the radionuclides involved. It appears that the viability of this alternative will be determined on a case-by-case basis and will be dependent on the needs and resources of the UF_6 plant owner and the requirements of NRC.

Analyses of radiation exposures and costs for SAFSTOR are presented in Section 11.3.4.

11.3.3 ENTOMB

ENTOMB of a U-fab plant requires its encasement in concrete to protect the public from radiation exposure until its radioactivity has reached levels permitting release of the facility for unrestricted use. It is a possible but not very reasonable alternative. The building is not structurally suited to entombment, therefore, the initial entombing process would be costly. Because the radionuclides present in the UF_6 plant have very long half-lives, the structure would have to be monitored and maintained in perpetuity, which is well beyond the time that required institutional control, could be expected to be effective (approximately 100 years is considered to be consistent with recommended EPA policy on institutional control for radioactivity confinement). Also, there would be no cost or safety advantage to ENTOMB, because DECON is simple, safe, and relatively inexpensive. In any event, the waste ponds would have to be removed and could not be entombed. ENTOMB is not a viable decommissioning alternative.

11.3.4 Summary of Radiation Safety and Decommissioning Costs

11.3.4.1 Radiation Safety

Residual radioactivity following inventory removal at a U-fab plant will be confined mainly to the interior parts of equipment and the ventilation system. The CaF_2 waste, containing some uranium, may have to be reprocessed or sent to a low-level waste burial ground.

The radioactivity in a U-fab plant is mostly due to ^{235}U and ^{234}U. External dose to decommissioning workers will be at plant background, which is about 1 mrem/hr. Because of the long half-life of ^{235}U, (approximately 7×10^8 years) this background will not be decreased appreciably by placing the plant in custodial safe storage for a time before deferred decontamination.

The approximately 270 kg of uranium that are still in the plant at shutdown contain about 8 kg of ^{235}U, which will be thinly dispersed over very large surface areas of the equipment and ventilation system. The possibility is remote that a worker at any particular location would contact a large concentration of ^{235}U. Nevertheless, some pieces of equipment will be more highly contaminated than others and the possibility exists that dust can be dislodged and suspended in the air where it will be inhaled. For this reason, appropriate protective clothing and face masks will likely be needed for decommissioning selected parts of the plant.

Occupational radiation exposure of workers performing the decommissioning activities results from external exposure for reasons similar to that discussed for PWRs in Section 4.3.1. Table 11.3-1 presents a summary of the radiation exposures that may result from each of the decommissioning alternatives. As can be seen from the table, the occupational exposures do not decrease as a result of using the SAFSTOR alternative. This is because of the long half-lives of the radionuclides present in the facility compared to the time the facility might be held in safe storage awaiting deferred decontamination. As can also be seen from Table 11.3-1, total estimated public exposures from decommissioning activities are very small. If the CaF_2 waste has not been removed and shipped to another plant for reprocessing, it may have to be packaged and shipped to a low-level waste burial ground for disposal. This would result in additional occupational and public radiation doses of 20 and 0.4 man-rem respectively.

A range of possible accidents that would result in released radioactivity is postulated. The largest releases are from loss of HEPA filters. This would result in the same quantities of release and radiation doses and have the same probabilities of occurrence with either decontamination alternative. A summary of the estimated doses to the public from accidents is shown in Table 11.3-2. Radiation doses to the public resulting from accidents are low enough to be considered insignificant.

Radioactive waste materials are packaged and shipped offsite for burial during decommissioning of the reference U-fab plant. The dominant radiation exposure pathway to transport workers and the public during transportation of radioactive wastes is external exposure for reasons similar to those discussed for PWRs in Section 4.3.1. The external dose for transportation is conservatively estimated to be 2.6 man-rem to transportation workers and 0.53 man-rem to the public for either DECON or SAFSTOR. These doses are based on regulations of the Department of Transportation governing radiation levels in shipments and on estimates of the distances of travel and lengths of time of exposure that workers and the public might expect. These doses are summarized in Table 11.3-1.

TABLE 11.3-2 Summary of Radiation Doses to the Maximum-Exposed Individual from Accidental Airborne Radionuclide Releases During Decommissioning Activities for Either Decommissioning Alternative(a)

Incident	Release to Atmosphere (μCi)	First-Year Dose, mrem		Fifty-Year Committed Dose Equivalent, mrem		Expected Frequency of Occurrence
		Bone	Lung	Bone	Lung	
Loss of Intermediate HEPA Filter After Duct Decontamination	2.7	2.3×10^{-3}	7.6×10^{-2}	4.[illegible] $\times 10^{-3}$	1.9×10^{-1}	High
Loss of Local Airborne Contamination Control, Loss of Vacuum Filter	0.70	6.0×10^{-4}	2.0×10^{-2}	1.1×10^{-3}	4.9×10^{-2}	High
Liquid Leak During Chemical Decontamination	4.5×10^{-3}	3.7×10^{-6}	1.3×10^{-4}	7.3×10^{-6}	3.1×10^{-4}	High

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(a) Adapted from Reference 1

The severity of accidents that may occur during transportation of radioactive waste depends on a number of factors, such as speed, kind of accident, and accident locations. Regardless of the decommissioning alternative, the same total amount of radioactive material will be transported. Thus, the possible release of radioactivity will be dependent on frequency and kind of accidents, as shown in Table 11.3-3.

TABLE 11.3-3 Estimated Frequencies and Radioactivity Releases for Selected Transportation Accidents(d)

Accident Description	Accidents per Dismantlement	Release (Ci)(b,c)	Radiation Dose for Maximum-Exposed Individual (rem)(a)			
			First-Year Dose		Committed Dose Equivalent	
			Bone	Lungs	Bone	Lungs
Minor Accident	2.3×10^{-2}	No Release	--	--	--	--
Moderate Accident	5.4×10^{-3}	1×10^{-7}	3.9×10^{-6}	1.3×10^{-4}	7.7×10^{-6}	3.2×10^{-4}
Severe Accident	1.4×10^{-4}	1×10^{-5}	3.9×10^{-4}	1.3×10^{-2}	7.6×10^{-4}	3.2×10^{-2}

(a) Maximum-exposed individual is assumed at 100 m from the site of the accident.

(b) Based on an inventory of 100 mCi, the expected maximum per truck shipment.

(c) Release fraction for respirable material for moderate and severe accidents are assumed to be 10^{-6} and 10^{-4}, respectively.

(d) Adapted from Reference 1.

11.3.4.2 Decommissioning Costs

Table 11.3-4 summarizes the estimated costs in 1978 dollars for the decommissioning alternatives analyzed in this report. All cost estimates include an added 25% for contingencies. For DECON, the decommissioning costs are estimated to be \$3.5 million. For custodial SAFSTOR, the total decommissioning cost is estimated to be \$8.9 million and \$17.5 million for 10-year and 30-year SAFSTOR, respectively. These SAFSTOR costs include \$0.78 million for preparation for safe storage, \$0.43 million per year for continuing care, and \$3.8 million for deferred decontamination. A present value analysis of decommissioning costs indicates a disincentive to defer decontamination for the reference case indicated, primarily because of the high cost of continuing care relative to DECON costs and the high cost of deferred decontamination due to the long half-lives of the radionuclides involved. Therefore, from a cost standpoint, it is probably to an operator's advantage to choose the DECON alternative and convert the building to other uses.

TABLE 11.3-4 Summary of Estimated Costs for Decommissioning the Reference U-fab Plant[a]

ITEM	Estimated Costs in Millions of 1978 Dollars DECON	SAFSTOR (Custodial) 10 year	 30 year
Preparation	NA	0.78	0.73
Continuing Care	NA	4.3	12.9
Decontamination[b]	3.5	3.8	3.8
Total[c]	3.5	8.9	17.5

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[a] Adapted from Reference 1.

[b] For SAFSTOR, this is deferred decontamination.

[c] Total does not include additional potential cost of contaminated CaF^2 disposal. This would add approximately $7 million to the total.

Most of the cost of decommissioning a U-fab plant will be for labor. A large portion of the labor costs will be for handwashing the ceiling, wall, and floor surfaces of the building. Equipment that is still serviceable will also be damp-wiped or flushed with detergent solutions or weak acid where hand wiping is not possible. Some spalling of concrete floors may be required in areas such as pump basins which have had contact with uranium solutions. Deferring decontamination adds to the total cost because of the cost of labor for continuing care, of reactivating full utility service and of holding licenses. It does not decrease the cost of eventual decontamination.

Of the total costs listed in Table 11.3-4, the cost of waste management is $0.6 million. This includes $0.2 million for low-level waste burial of contaminated equipment, building components, and concrete, and $0.4 million for disposal of the chemical waste sludge (non-radioactive) in a chemical waste burial ground. The CaF_2 waste will potentially be disposed of in a low-level waste burial ground, and removal, packaging, shipment, and burial would cost an additional $7 million.

11.4 ENVIRONMENTAL CONSEQUENCES

Because radiological effects are quite s[illegible] potential nonradiological effects will have the greater impact on the environment.

11.4.1 Nonradiological Safety

The area of greatest concern for the welfare of decommissioning workers is the calcium fluoride lagoons and storage pits. The very caustic nature of CaF_2 makes it necessary to protect the workers from contacting it on their skin and breathing the dust. The workers will therefore require protective clothing and respirators. The trucks used for transport to the burial ground will have the same risk of traffic accidents as with any other trucking operation, and the probability of accidents can be estimated from highway safety statistics. This probability is estimated to be 1.5×10^{-6} accidents per kilometer of travel.(4)

11.4.2 Commitment of Resources

The largest commitment of resources will be for space in chemical and low-level waste burial grounds. The burial volume of contaminated equipment, building components, and concrete is 1100 m^3, the burial volume of CaF_2 waste would be 29,600 m^3 (accounts for almost 3 acres of burial ground), and the burial volume of other chemical waste is 5300 m^3. Materials used up in decontaminating a U-fab plant will include cleaning supplies, such as detergents, clothes, mops, and brushes.

11.4.3 Socio-economic Effects

In decommissioning a U-fab plant, many of the same people that operated the plant can do the cleaning, but the dismantling and moving of equipment will be done by electricians, plumbers, mechanics, and equipment operators, most of whom will be hired or contracted. The socioeconomic effects of decommissioning, then, will come from the employment of these craftsmen. The total decontamination crew may be larger than the operating crew, and so for the period of decontamination, the economic input to the community will increase. In the case of custodial safe storage, the work force may decrease to a security and maintenance crew for the period of continuing care.

Because of the planning time needed to precede the decommissioning, changes in the number of employees will not be sudden or without warning, and people will have time to find other employment.

11.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

The options of DECON and SAFSTOR (custodial) both eventually end with the same results: a decontaminated facility that can be released for unrestricted use. The choice of an alternative generally depends on such considerations as dose, cost, proposed use of the site, and desirability of terminating the license. For a U-fab plant, due to the long lived nature of the radionuclides present, doses and costs are not reduced even when decontamination is deferred for 30 years, as can be seen from Tables 11.3-1 and 11.3-4. In addition since the cost and doses of continuing care is a major item and continues to increase with increasing safe storage time, the doses and cost associated with the complete SAFSTOR process exceed those for DECON. Therefore, DECON appears to be a more advantageous option. For the reasons given in section 11.3.3, ENTOMB is not considered a viable alternative.

There are about 20 fuel fabrication plants in the U.S., some of which are not now operating, and some of which manufactured fuel pellets but did not assemble rods and bundles. These plants are of various sizes and capacities and some produce highly enriched fuel for special purpose reactors. Because most of these plants are smaller than the reference plant, the cumulative impact of decommissioning all of them will be significantly less than 20 times the impact from decommissioning the reference plant.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

12.0 INDEPENDENT SPENT FUEL STORAGE INSTALLATION

The purpose of an independent spent fuel storage installation (ISFSI) is to store irradiated fuel assemblies from nuclear power reactors until an adequate disposal method is adopted, such as fuel reprocessing or disposal as high level wastes. The design of an ISFSI is similar to that of reactor spent fuel storage pools except that the storage capacity in significantly greater. Such a facility would have a storage capacity of about 5000 MT of spent fuel. The Department of Energy is presently evaluating the need and timing for a storage facility of this type.(1) Regulations (10 CFR 72) dealing with ISFSI are discussed in Section 1.4.1.

Currently no facility of this size has been built or licensed. A detailed report on the decommissioning of an ISFSI, similar to those prepared for other facilities discussed in this EIS, is planned for issuance in fiscal year 1982. For consideration in this EIS, the smaller storage facility at the Allied-Gulf nuclear plant at Barnwell, South Carolina, was scaled up to meet the assumed 5000 MT storage capacity and was used as a reference plant. For purposes of evaluating environmental impacts of decommissioning it was assumed to be located at the generic site described in Section 3.1. For the commercial sector, wet storage is contemplated as more probable in the immediate future. Dry storage is in too preliminary a stage of consideration for analysis at this time.

12.1 ISFSI DESCRIPTION

The ISFSI is designed to receive, store, and prepare for shipment irradiated fuel from light water power reactors. The spent fuel assemblies are stored at the reactors for at least one year and then shipped to the ISFSI in shielded casks by either truck or rail transport. The fuel assemblies are then unloaded from the casks under water and placed in storage racks in the fuel storage pool until their future disposition is determined.

The fuel storage pool has reinforced concrete walls and floors that are lined with stainless steel. It is filled with water to a depth of about 9 m (30 ft). The water, which provides both shielding and cooling for the radioactive fuel assemblies, is circulated through heat exchangers to remove decay heat and then through filters and ion exchange beds as necessary to remove both particulate and dissolved radionuclides. The resulting deionized water is very clear, allowing visual observation of the stored fuel assemblies. The radioactivity of the water is in the range of 10^{-5} to 10^{-2} μCi/mℓ.

The fuel assemblies are unloaded from the transfer casks in separate, smaller deep water cells that can be isolated to prevent interchange of the cask unloading pool water with the storage pool water. This avoids contamination of the storage pool from the shipping cask or a leaking fuel element thus reducing the required flow rate through the water purification system. Facilities for decontaminating the shipping casks before they leave the plant are provided. The contaminated solutions from the cask decontamination and other similar efforts are concentrated and the concentrates combined with ion exchange resins that are solidified and disposed of as low-level radioactive waste.

The major portions of the ISFSI are arranged as a total structural complex, as shown in Figure 12.1-1. The combined structures include an area about 210 m (700 ft) long and 150 m (500 ft) wide. The storage area is composed of one or more fuel pools, with a total capacity of 5,000 MT of irradiated fuel. The area occupied by the buildings containing radioactive material is about 3.2 hectares (8 acres). The whole complex occupies about 20 hectares (50 acres) enclosed by one or more security fences.

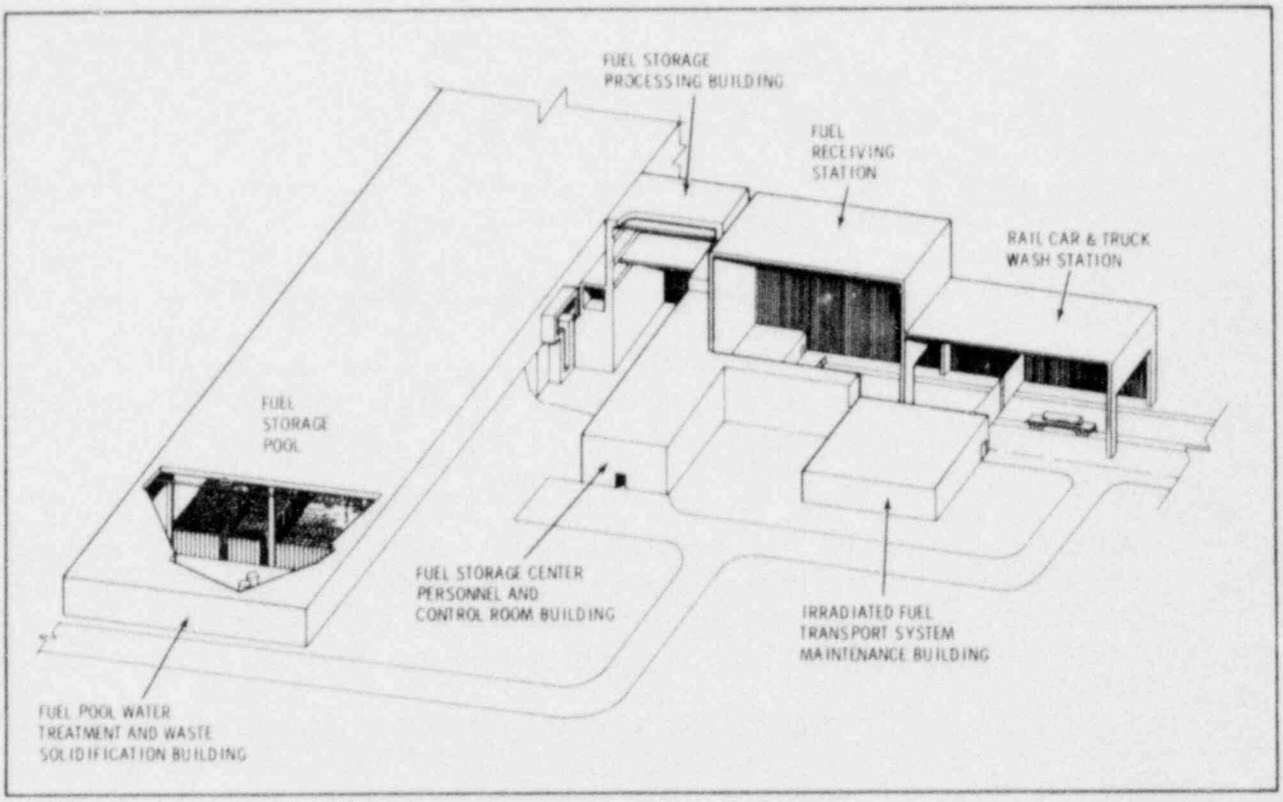

FIGURE 12.1-1. Independent Spent Fuel Storage Installation

12.1.1 Estimates of Radioactivity Levels at the Time of ISFSI Shutdown(2,3)

The sources of radioactivity in the pool water are activation products and fission products. The activation products are crud deposits and corrosion films on the fuel assembly surfaces. The fission products come from fuel assemblies with rods that failed while in service in the reactor or from intact fuel assemblies that adsorbed circulating fission products. Data on radionuclide concentrations in reactor storage pools is given here as background information. The principal activation products in reactor pool waters, their half-lives and production reactions are given in Table 12.1-1. The principal fission products in reactor pool waters are given in Table 12.1-2. Cesium, tritium, cerium, strontium, and the iodines are the principal fission products in reactor pools. The ISFSI accepts only aged fuel from the reactor, i.e., aged fuel is considered fuel that has been discharged from the reactor for greater than one year. For aged fuel the most significant isotopes from the standpoint of ISFSI pool waste management are ^{134}Cs, ^{137}Cs, ^{58}Co, ^{60}Co since shorter lived radionuclides will have decayed. The principal isotopes and their concentration ranges that have been experienced in reactor pools are given in Table 12.1-3.

TABLE 12.1-1. Principal Activation Products Released from Fuel Assemblies During Reactor Pool Storage

Nuclide	Half-Life	Production Reaction
^{51}Cr(a)	28 d	^{50}Cr(n-γ)
^{54}Mn(a)	310 d	^{54}Fe(n-p)
^{58}Co	72 d	^{58}Ni(n-p)
^{59}Fe(a)	45 d	^{58}Fe(n-γ)
^{60}Co	5.3 y	^{59}Co(n-γ)
^{65}Zn(a)	243 d	^{64}Zn(n-γ)
^{65}Ni(a)	2.5 h	^{64}Ni(n-γ)
^{187}W(a)	24 h	^{186}W(n-γ)

(a) Only significant at reactor pools.

TABLE 12.1-2. Principal Fission Products Released from Fuel Assemblies During Reactor Pool Storage

Nuclide	Half-Life
^{3}H	12.3 y
^{90}Sr	28.8 y
^{95}Zr-^{95}Nb	65 d-35 d
^{106}Ru-^{106}Rh	1.0 y-2.2 hr
^{131}I	8.05 d
^{134}Cs	2.1 y
^{137}Cs	30 y
^{140}Ba	12.8 d
^{144}Ce	285 d

TABLE 12.1-3. Radionuclide Concentrations Experienced in Reactor Fuel Storage Pools[a] (µCi/mℓ)

Nuclide	Current Spent Fuel Pool Experience With Zircaloy clad Fuel	Early Spent Fuel Pool Experience With Stainless Steel Clad Fuel
^{3}H	-	1×10^{-3}
^{54}Mn	-	1×10^{-5}
^{58}Co	5×10^{-6} to 3×10^{-5}	2×10^{-5} to 1×10^{-4}
^{60}Co	5×10^{-6} to 1×10^{-4}	1×10^{-5} to 1×10^{-4}
^{90}Sr	2×10^{-5}	
^{131}I	1×10^{-7}	1×10^{-6}
^{134}Cs	1×10^{-5} to 1×10^{-4}	3×10^{-4}
^{137}Cs	3×10^{-5} to 1×10^{-4}	5×10^{-4} to 1×10^{-3}
^{140}Ba	1×10^{-5}	
Alpha	$<1 \times 10^{-6}$	
Total, µCi/mℓ	1×10^{-7} to 1×10^{-3}	1×10^{-3} to 1×10^{-2}
Dose Rate,[b] mrem/hr	<1	<5

[a] At equilibrium conditions; higher values are generally present immediately following fuel discharge from the reactor.

[b] Dose rates at reactor pools may approach 40 to 100 mrem/hr on occasion during cleanup system malfunctions and following fuel discharges from the reactor.

The activation products come principally from neutron activation of corrosion products in the reactor primary coolant, which deposit as crud layers on fuel element surfaces (Fe_2O_3, Fe_3O_4, spinels, sometimes oxides of nickel and copper). Compared to BWRs crud layers generally are thinner and sometimes are almost absent on PWR fuel rods. The crud layers are believed to be the principal sources of contamination in the pool water. The corrosion products on Zircaloy clad rods (ZrO_2) also have low solubilities and generally resist spallation.

There are substantial differences in the inventories of radionuclides at reactor pools and at ISFSI pools. During refueling, reactor pool radioactivity levels increase due to the dissolved and particulate radionuclides in the reactor primary coolant, which mixes with pool water, and due to radionuclides released from fuel assembly surfaces. Short-lived radionuclides, such as certain iodine isotopes, appear in reactor pools, but not at ISFSI pools since they have time to decay prior to reaching the ISFSI pool. Tritium also is substantially higher in reactor pools since the major mechanism for its getting in reactor pools is mixing reactor primary coolant and the reactor pool water during refueling. Loose crud is released from the fuel element surfaces during handling in the reactor pool. Radioactivity levels at reactor pools often increase to ~10^{-2} µCi/mℓ during refueling, but can be controlled at 10^{-4} to 10^{-3} µCi/mℓ after refueling is completed. Radioactivity levels at ISFSI and R&D facility pools rise during receipt of fuel shipments, but are controlled at levels between 10^{-4} and 10^{-3} µCi/mℓ most of the time. Filtration and ion exchange are the principal methods for controlling pool water radioactivity. At most Canadian and some U.S. pools, the ion exchange bed also serves as the filter. Vacuuming is another method which removes radioactive particles from the bottom of the pool.

The fuel elements received at the ISFSI will be aged fuel (at least 1 year since reactor discharge) and will be rinsed prior to storage in the pool. Experience at the General Electric Morris operation(3) indicates that the pool water will contain the principal contaminants shown in Table 12.1-4. Heavy particles and crud will tend to form a layer on the bottom of the pool that is amenable to vacuum cleaning.

Mechanical damage appears to be a minor factor in fuel element degradation. Fuel elements that developed defects in-reactor have been stored, shipped, and reprocessed without major problems. Radiation releases from

TABLE 12.1-4. Radionuclide Concentrations Experienced at the G. E. Morris Storage Pool

Nuclide	Concentration (μCi/mℓ)
^{58}Co	5×10^{-4}
^{60}Co	1×10^{-3}
^{134}Cs	1×10^{-4}
^{137}Cs	5×10^{-3}

the defects generally are low and usually permit handling of the fuel on the same basis as intact fuel. If necessary, badly damaged fuel can be stored in water-tight cans.

12.2 ISFSI DECOMMISSIONING EXPERIENCE

To date, there has been no experience in the complete decontamination of a commercial ISFSI. However, in November 1971, Nuclear Fuel Services (in West Valley, New York) cleaned a fuel storage pool in which 150 failed N-reactor fuel elements had been stored from 1968 to 1970. The fuel pool was drained and the painted concrete bottom (no steel liner) was vacuumed and scrubbed with brushes. The radiation levels were reduced to about 150 mR/hour, including some radiation from corrosion products absorbed on the aluminum storage racks (not cleaned). When the pool was refilled, the water radioactivity levels returned to between 10^{-4} and 10^{-3} μCi/mℓ from a previous high of about 10^{-2} μCi/mℓ.

It is to be expected that the radiation exposures to the work force will be kept low during decommissioning by the use of long handled tools used for decontamination, installation of temporary shielding and similar means.

12.3 DECOMMISSIONING ALTERNATIVES

Once an ISFSI has reached the end of its useful operating life it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing of all radioactive materials in excess of levels which would permit unrestricted use of the facility. Several alternatives are considered here as to their potential for satisfying this general requirement for decommissioning. The decommissioning alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB.

The alternative used depends on such considerations as cost, dose, proposed use of the site and desirability of terminating the license. The assumptions made in the evaluation of decommissioning alternatives for an ISFSI include:

1. All spent fuel and any other stored radioactive materials are removed from the storage pool area to an off-site disposal facility prior to decontamination.

2. The water in the pool is continuously circulated through the ion exchange and filter cleanup system to remove the maximum amount of radioactivity possible during the life of the facility.

3. The 5,000 MT capacity of the pool is filled over a period of 5 years and remains at capacity during the rest of the pool life (20 to 40 years).

4. Fuel elements evolving excessive amounts of fission product activity during storage are isolated and canned.

5. Any accidental contamination of the site is cleaned up immediately.

6. The potentially contaminated part of the facility occupies about 3.24 hectares (8 acres).

The decommissioning of an ISFSI after 20 to 40 years of use is expected to be relatively simple compared to a reactor or reprocessing plant. The radionuclides expected to be present in an ISFSI (fission and activation products) have relatively short half-lives, as shown in Tables 12.1-1 and 12.1-2, and therefore will decay during the operating life of the facility (with the exception of the cesium and strontium). Tritium is not expected to be present to any extent in the ISFSI since there is insignificant mechanism for its production in an ISFSI pool.

The decommissioning of the ISFSI could be performed using any of the alternatives described above. However, in view of the relatively low radiation fields to be encountered by the decommissioning crew, it appears that DECON would be the most viable option.

12.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use.

DECON is advantageous because it allows for termination of the NRC license shortly after cessation of facility operations and removes a radioactive site. DECON is advantageous if the site is required for other purposes or if the site is extremely valuable. It is also advantageous in that the facility operating staff is available to assist with decommissioning and that continued surveillance is not required.

The first step of each of the decommissioning alternatives is the chemical decontamination of the equipment. In the case of DECON, an extensive flushing procedure would be used to remove the maximum amount of contamination, thus reducing occupational exposure to a minimum. Chemical decontamination for the other alternatives might be less extensive, depending on the continuing care period desired.

The initial decontamination of an ISFSI would tend to divide itself into three phases:

1. Removal and disposal of the deionized water from the storage pool.

2. Decontamination of the storage pool, including the cask unloading and decontamination areas.

3. Decontamination of the water cooling and cleanup systems and the low-level waste solidification and packaging systems.

In the first phase, the pool water would be disposed of by putting it through the deionizers and filters until it meets the environmental disposal specifications. As the water is lowered in the pool, high-pressure sprays would be used to clean the walls and equipment (storage racks, handling equipment, etc.). When the water is at about the 2m level, the floor would be vacuumed to remove the heavy particles. The rest of the water would then be disposed of to the environs after cleanup.

During the second phase, additional decontamination would be done by high-pressure spraying with the appropriate chemicals (e.g., detergents, acids, or appropriate decontamination agents). The low-level waste generated by the decontamination efforts would be concentrated as much as possible in the waste evaporator and then solidified for disposal in a low-level waste burial ground. At this point, the radiation background would be about 1 to

10 mR/hour, with "hot" spots reading up to 100 mR/hour.(4) Radiation surveys would then be made with spot decontamination as necessary. It is estimated that, because of low radioactivity levels, a large proportion of the stainless steel equipment would be releasable to the public domain and therefore might be salvageable.

In the third phase, the more highly contaminated equipment (i.e., coolers, deionizer, filters, evaporator heat exchangers, and attached piping) would probably need additional decontamination flushes to further reduce their radioactivity. It is assumed as part of good operational practice and decommissioning facilitation that the water coolant systems are periodically decontaminated.(3) These have residual buildup of ^{60}Co which could result in a background of a few R/hr over the facility lifetime. However, proper periodic decontamination will reduce this to tens of mr/hr. The final flushes through the evaporator and solidification unit would be followed by a comprehensive radiation survey of the total facility. It is estimated that as much as 75% of the water treatment and waste systems would have to be disposed of to low-level waste burial grounds. However, if vessels like the waste evaporator were cut into pieces, spot chemical decontamination, vibratory finishing, or electropolishing could reduce the amount of material to be disposed of to burial to less than 50%.

For DECON, final decontamination to reduce radioactivity to levels low enough for unrestricted use of the facility would follow the extensive chemical decontamination effort. It is possible that a large percentage of the stainless steel equipment would be clean and releasable to the public domain. However, because of the rack design, it may be very difficult to certify that all surfaces were uncontaminated and thus it might be necessary to dispose of the racks to a low-level waste burial ground. In the future, these racks might be reduced to metal ingots, the ingots sampled, and a determination made as to the state of contamination. The noncontaminated ingots would return to the public domain, while the contaminated ones would be buried. Less complex equipment would be cut into pieces that could be surveyed and spot decontaminated, vibratory cleaned, or electro-polished as necessary. All contaminated materials would be reduced in size as appropriate, boxed, and shipped to a low-level waste burial ground for disposal.

The pool liner would then be removed and disposed as above, with an estimated 75% salvageable and 25% sent to burial. The concrete walls and floor under the liner would then be surveyed and decontaminated as necessary. Hot spots would be removed by chipping the concrete away and sending the contaminated fragments to the burial ground. Since the pool had a full stainless steel liner, very little concrete (less than 10%) is expected to be sent for burial.

When the fuel pools have been decommissioned, the rest of the equipment that contains radioactivity would be removed. Again, contaminated equipment that can be decontaminated to release limits using reasonable efforts (i.e., chemical, vibratory finishing, or electropolishing decontamination techniques) would be salvaged and the remaining equipment would be disposed of at a low-level burial ground. The site area itself would be surveyed, any hot spots decontaminated and then released. Any radioactive materials buried on-site may have to be removed and transported to a low-level waste burial ground.

Once all contaminating radionuclides above levels permitting unrestricted use have been removed from the facility, and a certifcation survey made, the facility would be released by NRC to the owner for unrestricted use.

Occupational radiation exposure of workers performing the decommissioning activities results from external exposure for reasons similar to that discussed for PWRs in Section 4.3.1. The estimated occupational radiation dose from DECON is 72 man-rem, as shown in Table 12.3-1. The public radiation dose is estimated to be negligible.

TABLE 12.3-1. Summary of Occupational Exposures for Routine Decommissioning of the Reference ISFSI (man-rem)

	DECON	SAFSTOR 10 year	SAFSTOR 30 year	SAFSTOR 100 year	ENTOMB
Preparation	NA	35	35	35	NA
Continuing Care	NA	5	15	50	NA
Decontamination[(a)]	72	37	37	37	15
	72	77	87	122	15

[(a)] For SAFSTOR, this is deferred decontamination.

The material transported to the low-level burial grounds during DECON is expected to be low enough in radioactivity that there will be negligible exposure to either the public or to the personnel handling the shipment. Thus, the potential for the release of radioactivity to the public from an accident is small.

The cost of DECON is estimated to be $4.6 million in 1978 dollars as shown in Table 12.3-2 and summarized in Table 12.3-4. The costs include staff labor; subcontractor activities; equipment and materials; contaminated waste packaging, transportation, and disposal; and utilities, services, and other overheads. The costs are based on the decommissioning procedures presented in Section 7.1 through 7.7 of NUREG-0278(4) and a scaling factor to allow for the increased capacity of ISFSI. A 25% contingency factor is added to the cost estimates.

TABLE 12.3-2. Summary of Cost Estimates for DECON

Expense Item	Cost (Thousands of 1978 dollars)
Support Staff Labor	1 100
Decommissioning Worker Labor	1 700
Subcontractor Activities	74
Equipment and Materials	293
Shipping and Waste Disposal	243
Utilities, Taxes and Other Expenses	300
Subtotal	3 712
25% Contingency	928
Total	4 640

Although all racks are expected to be clean, it is assumed that they must be shipped to waste burial because of the inability to adequately survey for radiation. If this material could be reduced to ingot form and sampled, a large savings in scrap stainless steel could be realized.

12.3.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) an ISFSI in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

In the ISFSI the fuel pools are surrounded by a relatively lightly constructed building (i.e., mostly steel frame members covered with steel or transite siding and roof). Sealing this building off to prevent any type of forced entry is difficult. However, from a radioactivity exposure viewpoint, the dose rates in the building are very low (1 to 10 mR/hour on an average), and it would take 4 days of close contact with the contaminated material to obtain a dose of 1 rem. Thus, it is possible that the building structure affords adequate protection for such a low exposure rate.

The water treatment and waste processing systems would be contained in cells with concrete walls that lend themselves to adequate sealing techniques.

Once the facility has been flushed and sealed, the continuing care period begins. Generally, the primary advantage of SAFSTOR for most nuclear facilities is that it results in reduced occupational exposure compared to DECON. However, for the ISFSI, since the short half-lived radionuclides have decayed and the occupational doses from decontamination are expected to be very low (only small amounts of ^{137}Cs and ^{60}Co are left), there is little incentive from the standpoint of reducing occupational dose to delay decontamination. Any delay in decontamination involved in SAFSTOR would result in the loss of an experienced operating crew, about $46,000 expense each year for continuing care, and the inability to use the present site for other purposes. In addition the licensee is required to maintain a material license and to meet its requirements at all times during safe storage thus contributing to the number of sites dedicated to radioactive confinement for an extended period. However SAFSTOR would be advantageous in situations where there were overriding facility reuse or land use considerations.

The occupational radiation dose due to external exposure from SAFSTOR is 72 man-rem plus 0.5 man-rem per year of safe storage (Table 12.3-1). Public radiation dose is expected to be negligible. The material transported to the low-level burial grounds during SAFSTOR is expected to be low enough in radioactivity that there will be negligible exposure to either the public or to transportation workers. Thus, the potential for the release of radioactivity to the public from an accident is small.

The cost estimates for SAFSTOR preparation ($2,184,000), continuing care ($46,000 per year), and deferred decontamination ($3,706,000) are given in Table 12.3-3 and summarized in Table 12.3-4. These costs are based on a thorough cleanup effort during the preparation period. The deferred decontamination costs are nearly the same as the decontamination costs for DECON. This is because radioactivity levels in the ISFSI are low at shutdown, would not change appreciably during the continuing care period, and therefore the same procedures would be used during DECON and during deferred decontamination. The continuing care costs are based on part-time help for maintenance and supervision, but one full-time security man.

12.3.3 ENTOMB

ENTOMB of an ISFSI requires its encasement in concrete to protect the public from radiation exposure until its radioactivity has decayed to levels permitting release of the facility for unrestricted use. As shown in Tables 12.1-1 through 12.1-3, the major radionuclides of concern have all decayed during the 15 to 40-year life of the ISFSI, with the exception of small amounts of ^{60}Co and ^{137}Cs. While the long-lived actinides are very insoluble in water and are generally not expected to be present, a possibility exists that some small amounts of solubilization or colloidal formation occur. Over a period of 15-40 years such material might accumulate in the porous concrete walls of the fuel pool if a small amount of leakage occurred through the pool liner. Removal of the steel liner and a difficult certification would be required to assure that long-lived radionuclides were not present. Thus ENTOMB of an ISFSI could require surveillance in perpetuity which is an unacceptable condition. Even if certification were possible, the expected small amounts of ^{137}Cs would require 200 to 300 years to decay to levels permitting release of the facility for unrestricted use. This would require surveillance beyond the time that is considered reasonable for administrative controls (approximately 100 years is considered to be consistent with recommended EPA policy on institutional control for radioactivity confinement) and contribute to waste burial site proliferation. Consideration of ENTOMB for comparative purposes with the other possible alternatives in terms of dose and cost impact, it is assumed that all contaminated equipment is placed in the bottom of the storage pool and covered with 1.8 m (6 ft) or more of concrete.

TABLE 12.3-3. Summary of Cost Estimates for SAFSTOR (Safe Storage Preparation, Continuing Care, and Deferred Decontamination)

Expense Item	Cost (Thousands of 1978 Dollars) Safe Storage Preparation	Continuing Cost Per Year	Deferred Decontamination
Support Staff Labor	434	24	780
Decommissioning Worker Labor	1 074	--	1 443
Subcontractor Activities	18	--	39
Equipment and Materials	65	2.6	277
Shipping and Waste Disposal	8	--	243
Utilities, Taxes and Other Expenses	148	10	183
Subtotal	1 747	37	2 965
25% Contingency	437	9	741
Total	2 184	46	3 706

TABLE 12.3-4 Summary of Estimated Costs for Decommissioning the Reference ISFSI

	Estimated Costs in Millions of 1978 dollars				
		SAFSTOR			
Item	DECON	10 year	30 year	100 year	ENTOMB
Preparation	NA(b)	2.2	2.2	2.2	3.25
Continuing Care	NA	0.46	1.38	4.6	-(c)
Decontamination(a)	4.6	3.7	3.7	3.7	NA
	4.6	6.36	7.3	10.5	3.25(c)

(a) For SAFSTOR, this is deferred decontamination.

(b) NA - not applicable.

(c) Does not include the $0.046 million per year for surveillance.

Occupational radiation exposures for ENTOMB are estimated to be approximately 15 man-rem (Table 12.3-1). These doses are lower than for DECON since no extensive hand decontamination would need to be done to the fuel storage pools and since other contaminated equipment would be placed in the pool area with only minimum decontamination and size-reduction efforts. The dose reduction compared to DECON is considered to be of marginal significance to health and safety. Public exposure would be negligible.

The estimated cost of ENTOMB is about $3.25 million with $442,000 of this cost for concrete (Table 12.3-5) and an additional cost of about $46,000 per year for surveillance. In this estimate the facility is assumed to be decontaminated in a manner similar to that used at the beginning of DECON. In actual practice, only that decontamination necessary to limit personnel exposure would be done. The concrete in the pools was calculated to cover the fuel racks by 1.8 m (6 ft), which should be more than adequate to protect the public and make any inadvertent entry impossible. The resulting structure, after the concrete filling, would resemble a strong foundation (with a 2.4- to 2.7-meter or 8- to 9-foot deep basement) upon which a new structure could be built for a new process facility. Some additional costs ($8 to $12 million minimum) would be incurred for surveillance and maintenance during a 200 to 300 year period. However, surveillance costs could continue in perpetuity.

TABLE 12.3-5. Summary of Cost Estimates for ENTOMB[(a)]

Expense Item	Cost (Thousands of 1978 Dollars)
Decontamination of Equipment and Pools	2 100
Moving Equipment into Pool area	48
Fill Pools with Concrete	400
Site Survey	13
Subtotal	2 600
25% Contingency	650
Total	3 250

(a)Does not include the $46,000 annual surveillance cost.

12.4 ENVIRONMENTAL CONSEQUENCES

The decommissioning of an ISFSI will have only minor negative environmental impacts. This section discusses waste disposal and nonradioactive impacts. The occupational and public radiation doses are discussed in Section 12.3. Discussion of costs are also included in Section 12.3.

12.4.1 Industrial Safety

The worker lost-time injuries and fatalities per given alternative are summarized in Table 12.4-1.

TABLE 12.4-1 Estimated Worker Lost-Time Injuries and Fatalities for Each Decommissioning Alternative

Mode	Lost-Time Injuries	Fatalities
DECON	0.59	0.0029
SAFSTOR		
Safe Storage Preparation	0.15	0.0013
Continuing Care	<0.1	<0.0001
Deferred Decontamination	0.25	0.0013
ENTOMB	0.15	0.0008

Lost-time injuries and fatalities from nonradiation transportation accidents for all aternatives are 0.03 and 0.002, respectively.

12.4.2 Waste Disposal

The volume of low-level waste to be transported to a low-level burial site would vary from nearly zero for ENTOMB to about 1,020 m^3 (11,000 ft^3) for DECON. ENTOMB, in effect, would create a low level waste burial site out of the ISFSI. SAFSTOR could result in slightly more material than for DECON.

The 1,020 m^3 (11,000 ft^3) of waste requiring burial would represent the use of what could be irretrievable land (approximately 1 acre). This is the largest negative impact in the ISFSI decommissioning process. This loss of land use, however, is more than balanced by the return of the ISFSI site (50 acres) for the public use.

12.4.3 Additional Effects

In summary, all alternatives appear to have only a small negative environmental impact. This impact is from the burial of radioactive waste, the use of expendable supplies, and the small amount of noise from operation of heavy equipment during decommissioning. The return of the 20-hectare (50-acre) site for the public use is a positive environmental impact. The socioeconomic impacts are mainly from the shutdown (not decommissioning) of the storage facility, which would reduce the income of the community and region because of the loss of about 30 to 40 jobs.

12.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

A comparison of the decommissioning alternatives discussed in this section is given in Table 12.5-1. The choice of an alternative generally depends on such considerations as dose, cost, proposed use of the site, and desirability of terminating the license. The table shows DECON to be a more viable option than SAFSTOR, considering all items. Since all of the site would be free of contamination, it would be possible to release it for public use. ENTOMB appears to be the least viable option. Aside from contributing to the problems associated with increased numbers of radioactive waste burial sites, the minimum required surveillance costs are approximately $6 to $8 million which, when combined with the $3.25 million estimated for decontamination, make this option the most costly.

TABLE 12.5-1. Values of Parameters for Comparison of Decommissioning Alternatives

		SAFSTOR			
	DECON	10 Years	30 Years	100 Years	ENTOMB
Total Cost (millions $) Constant 1978 Dollars	4.6	6.4	7.3	10.5	3.25[(a)]
Occupational Radiation Dose (man-rem)	72	77	87	122	15
Potential Public Radiation Dose (man-rem)	neg	neg	neg	neg	neg
Potential Industrial Accident Injuries	0.57	0.40[(b)]	0.40[(b)]	0.40[(b)]	0.08
Potential Industrial Accident Fatalities	0.0029	0.0026[(b)]	0.0026[(b)]	0.0026[(b)]	0.0005
Manpower Expenditures (cumulative man-years)	69	74	85	125	25
Land Area Committed - hectares (acres)	0.4(1)	0	0.8(2)	0.8(2)	0.4(1)

(a) The surveillance costs of ENTOMB is estimated at about $46,000 per year. This cost would be expected to decrease over the years until terminated after 200-300 years, adding approximately $6 to $8 million to the cost of ENTOMB.

(b) Safe storage preparation and deferred decontamination were combined. Continuing care is very small.

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3. K. J. Eger and G. E. Zima, Commentary on Spent Fuel Storage at Morris Operation, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, NUREG/CR-0956 (PNL-3065), July 1979.**

4. K. J. Schneider and C. E. Jenkins, Technology, Safety, and Cost of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.***

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*Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

**Available for purchase from the GPO/NRC Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

***Available for purchase from the National Technical Information Service.

13.0 NUCLEAR ENERGY CENTER

The facilities discussed in the preceding sections are representative of single facilities located on separate, dispersed sites. Recent literature, however, has discussed the possibility of locating multiple facilities on a single site.(1-3) Possibilities range from a small site containing the now familiar pair or quartet (quad) of nuclear reactors to a very large site holding up to 40 reactors, and other fuel cycle facilities as well. The 1974 AEC study(1) contemplated up to 40,000 MWe of generating capacity on a single site, together with reprocessing plants, enrichment plants, and waste handling and storage facilities. The 1975 NRC study(2) contemplated power plant centers, fuel-cycle centers, and combined centers. The power-plant center would consist of 10 to 40 reactors of 1200 MWe capacity each; the fuel-cycle center would consist of fuel reprocessing plants, mixed oxide fuel fabrication facilities, and radioactive waste management facilities; and the combined center would contain both reactors and other fuel cycle facilities. A more recent article(3) examines some of these alternatives and argues for a smaller number of large sites containing multiple facilities, as opposed to a larger number of dispersed sites, each containing relatively few facilities. PNL is presently preparing a study of the technology, safety, and costs of decommissioning a nuclear energy center.(4) Among the subjects explored in the PNL study will be the use of interim storage of waste at the nuclear energy center. In particular, the possibility of storage of high activity waste until its major short-lived isotopes have significantly decayed (e.g., ^{60}Co) would be a serious consideration. Moreover, a modular construction concept, whereby highly radioactive components such as the pressure vessel could be removed intact (and temporarily stored onsite to allow for dose reduction through decay) will also be explored. Through such modular construction approaches, facilities could be more easily decommissioned or refurbished.

It is the purpose of this section to investigate on a preliminary basis whether significant decommissioning differences might exist between a single reactor on a site and one at a multiple reactor facility and whether this could have an effect on regulatory considerations. Accordingly, an attempt was made to exaggerate any possible differences that might occur in the decommissioning activities through the choice of a very large nuclear energy center which, over its operational lifetime, consists of the staged construction of 40 1200-MWe reactors, 2 independent spent fuel storage installations (ISFSI), and permanent nuclear waste disposal facilities adequate for the lifetime of the nuclear energy center. It is recognized that a dedicated nuclear energy center will not remain operational in perpetuity but rather be limited to a possible existence of several hundred years. However, it is not unreasonable for comparative purposes to assume that even long-lived wastes, which might require either intermediate or deep geologic disposal, can be accommodated onsite. For illustrative purposes, such a nuclear energy center might be placed at the Hanford Reservation, in Richland, Washington(5). Fuel reprocessing plants are not considered in this section because fuel reprocessing is not current policy. Uranium fuel fabrication plants and uranium hexafluoride conversion plants are not considered because of their minor environmental impact.

Preliminary results of the PNL study indicate that the conclusions reached in the more restrictive analysis presented in this section do not differ significantly from the more general ones presented in earlier chapters for single reactors.

13.1 NUCLEAR ENERGY CENTER DESCRIPTION

No commercial nuclear energy center exists today, so it is necessary to develop a reasonable model. Forty 1200-MWe reactors could be constructed on a single site at 2-year intervals without unduly disrupting the socio-economic structure of the surrounding area, provided that a skilled labor supply was available and that public services were already established in the surrounding communities for approximately 100,000 people. No more than five reactors would be under construction at any one time, and no more than two need be undergoing active decommissioning procedures at one time. Also, no more than 20 reactors (24,000 MWe) would be operating at any one time, assuming an operating lifetime of 40 years. Two ISFSIs would be required, and could be decommissioned at different times. We assume, for comparative purposes, that burial facilities for all nuclear wastes generated at the center would be available onsite and that the facilities would be final repositories.

13.1.1 Site Description

The generic fuel cycle facility site described in Section 3.1 is considered descriptive of a nuclear energy center site. If one sites 40 reactors (with only 20 operating at one time) and allows 1 acre per MWe (Ref. 2, Executive Summary, p. 9) to avoid major potential impact from heat dissipation, then a land area of 97 km^2 (37.5 square miles, or 24,000 acres) would suffice for a nuclear energy center that contains space for the reactors themselves. Approximately 24.3 km^2 additional space (9.4 square miles, or 6,000 acres) would easily allow adequate space for nuclear waste burial, for two ISFSIs, and for later addition of other fuel cycle facilities, if required.

The river flowing through the generic fuel cycle facility site with its average flow rate of 1420 m^3/sec (50,000 ft^3/sec) would probably be adequate for the nuclear energy center.

The site would have to be suitable for shallow-land burial of nuclear waste and probably also for deep geologic disposal. Otherwise, the advantage of lessened waste transportation impact would be lost.

13.1.2 Facility Description

The site would contain forty 1200-MWe PWRs, two 5000-metric ton (MT) ISFSIs, and facilities suitable for the disposal of 3.2 million m^3 (112 million ft^3) of radioactive waste.[a] Approximately 80% of this waste would come from reactor operations, while 20% would come from decommissioning activities. The reactors could be PWRs or a combination of BWRs and PWRs. We assume PWRs here for simplicity of the analysis. With the exception of deep geologic disposal and shallow-land low level waste disposal, these individual facilities are discussed in Sections 4, 5, and 12.

13.1.3 Construction and Operation Sequences

Ease of decommissioning depends on the timing of construction and operation of the nuclear energy center. One possibility is to begin reactor construction at 2-year intervals, to allow 10 years for construction, and to allow 40 years for operation. With this sequence the first reactor would be ready for decommissioning at the beginning of the 50th year, while at the same time reactors 2 through 21 would be operating, and reactors 22 through 26 would be under construction (begin counting at the beginning of construction of reactor 1). At no time would more than five reactors be under construction or would more than 20 be in operation. At the end of its operating lifetime each reactor could be decommissioned through the DECON, SAFSTOR, or ENTOMB alternatives or converted to another use. All reactors would be finished operating and in some stage of decommissioning by the 129th year. This scenario is depicted graphically in Figure 13.1-1.

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[a] From Table 4.4-1 of this report and Table 2 of Reference 6.

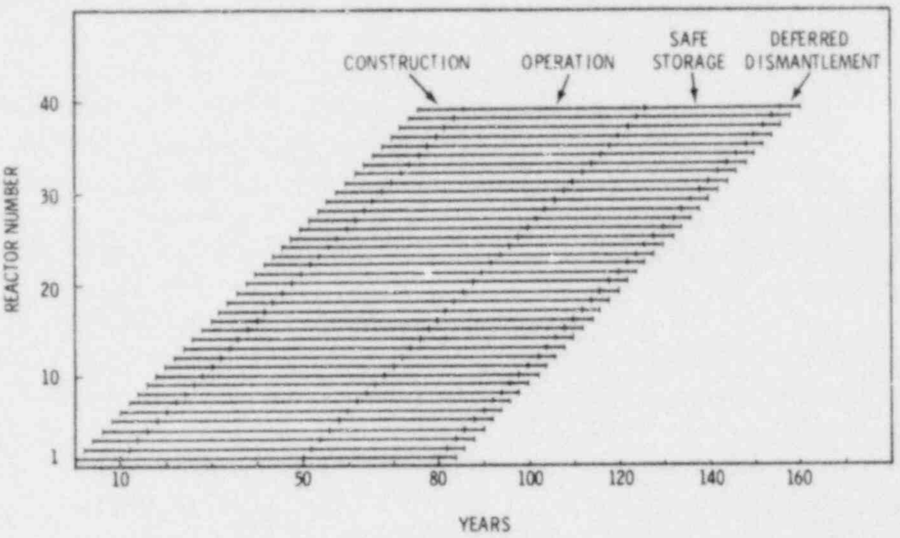

FIGURE 13.1-1. Possible Nuclear Energy Center Construction, Operation, and Decommissioning Schedule (reactors only)

One 5000-MT ISFSI would be barely adequate to handle the discharged fuel and store it for at least 10 years prior to disposal. We have assumed two here to provide additional flexibility. The first ISFSI would need to be available by about the 10th operating year (20th year of the cycle).

13.2 NUCLEAR ENERGY CENTER DECOMMISSIONING EXPERIENCE

No commercial energy centers have been constructed, therefore there is no decommissioning history to report. Studies are underway, however, on decommissioning military nuclear sites that contain several reactors, fuel fabrication facilities, reprocessing facilities, and waste burial grounds. Histories of decommissioning individual commercial nuclear fuel cycle facilities are given in the preceding sections.

13.3 DECOMMISSIONING ALTERNATIVES

Once a reactor has reached the end of its useful operating life it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing of all radioactive materials in excess of levels which would permit unrestricted use of the facility. The nuclear energy center offers more decommissioning options than do facilities located on dispersed sites, both because the facilities could be efficiently decommissioned one after another and because the facilities are located on a site that is presumably to be controlled for several hundred years.

For the purpose of this discussion, we assume that the model site contains the facilities described in Section 13.1.1, and that they were constructed in the sequence discussed in Section 13.1.3. The alternatives considered here are DECON, SAFSTOR, and ENTOMB.

13.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of DECON procedures. The end result is the release of the site and any remaining structures for unrestricted use.

For DECON, each reactor could be decontaminated to radioactivity levels permitting release of the facility for unrestricted use at the end of its 40-year operating lifetime. All 40 reactors would undergo DECON in sequence and, assuming construction takes 10 years and DECON 4 years, the first reactor would complete DECON by the end of the 54th year and the 40th reactor would complete DECON by the end of the 132nd year (see Figure 13.1-1). Because the waste disposal facility is located onsite, occupational radiation dose from transportation activities would be reduced, and public radiation dose from transportation activities would be eliminated. Thus, the public radiation dose from all reactor activities would be essentially zero, and occupational radiation dose per reactor would be reduced from 1183 man-rem to 1091 man-rem. Occupational and public radiation doses from DECON of the ISFSIs would not change because the occupational and public radiation doses from transportation activities are already negligible (see Section 12). The estimated radiation doses per facility from DECON of the nuclear energy center are given in Tables 13.3-1 and 13.3-2. These values may be compared to the values in Tables 4.3-2 and 12.3-1 (no change for the ISFSI), which are for individual facilities located on dispersed sites. In calculating the radiation dose from decontaminating a nuclear energy center, no credit was taken for efficiencies that might develop from repetitive decontamination. These efficiencies could easily reduce the radiation dose from decontaminating the newer facilities.

TABLE 13.3-1. Estimated Radiation Dose from Decommissioning Each PWR in a Nuclear Energy Center (Man-Rem)[a]

		SAFSTOR			ENTOMB	
	DECON	10 Years	30 Years	100 Years	Internals Included	Internals Removed
Occupational Exposure						
Safe Storage Preparation	NA[c]	279	279	279	NA	NA
Continuing Care	NA	10	14	14	neg.[b]	neg.
Decontamination	1 083	329	24	1	NA	NA
Entombment	NA	NA	NA	NA	900	1000
Safe Storage Preparation Truck Shipments	NA	1	1	1	NA	NA
Decontamination Truck Shipments	8	2	neg.[b]	neg.	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	2	2
Totals	1 091	621	318	295	900	1000
Public Exposure						
Safe Storage Preparation	NA	neg.	neg.	neg.	NA	NA
Continuing Care	NA	neg.	neg.	neg.	neg.	neg.
Decontamination	neg.	neg.	neg.	neg.	NA	NA
Entombment	NA	NA	NA	NA	neg.	neg.
Safe Storage Preparation Truck Shipments	NA	neg.	neg.	neg.	NA	NA
Decontamination Truck Shipments	neg.	neg.	neg.	neg.	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	neg	neg
Totals	neg.	neg.	neg.	neg.	neg.	neg

(a) Values exclude radiation dose from disposal of last core.

(b) Negligible.

(c) Not applicable to this decommissioning alternative.

The cost per facility for DECON of a nuclear energy center is reduced below the cost for DECON of equivalent facilities on dispersed sites (compare Tables 13.3-3 and 13.3-4 with Tables 4.3-1 and 12.3-2). This is because the costs of transporting nuclear wastes and of decommissioning planning are reduced. Waste disposal is assumed to take place onsite; therefore, the transportation cost of each shipment is small. Planning would need to be carried out in detail only once, and then refined with experience, assuming the facilities undergoing DECON were

TABLE 13.3-2. Estimated Radiation Dose from Decommissioning each ISFSI in a Nuclear Energy Center (in Man-Rem)

	DECON	SAFSTOR 10 Years	SAFSTOR 30 Years	SAFSTOR 100 Years	ENTOMB
Occupational Exposure					
Safe Storage Preparation	NA[b]	35	35	35	NA
Continuing Care	NA	5	15	50	neg.
Decontamination	72	37	37	37	NA
Entombment	NA	NA	NA	NA	15
Safe Storage Preparation Truck Shipments	NA	neg.	neg.	neg.	NA
Decontamination Truck Shipments	neg.[a]	neg.	neg.	neg.	NA
Permanent Entombment Truck Shipments	NA	NA	NA	NA	NA
Totals	72	77	87	122	15
Public Exposure					
Safe Storage Preparation	NA	neg.	neg.	neg.	NA
Continuing Care	NA	neg.	neg.	neg.	neg.
Decontamination	neg.	neg.	neg.	neg.	NA
Entombment	NA	NA	NA	NA	neg.
Safe Storage Preparation Truck Shipments	NA	neg.	neg.	neg.	NA
Decontamination Truck Shipments	neg.	neg.	neg.	neg.	NA
Entombment Truck Shipments	NA	NA	NA	NA	neg.
Totals	neg.	neg.	neg.	neg.	neg.

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[a] Negligible.
[b] NA-Not applicable for this decommissioning alternative.

TABLE 13.3-3. Estimated Costs of Decommissioning each PWR in a Nuclear Energy Center ($ Millions)[a,b]

		SAFSTOR			ENTOMB	
Item	DECON	10 Years	30 Years	100 Years	Internals Included	Internals Removed
Entombment	NA[c]	NA	NA	NA	18.9	25.1
Safe Storage Preparation	NA	8.2	8.2	8.2	NA	NA
Continuing Care	NA	0.3	1.1	3.9	0.020/yr	0.020/yr
Decontamination	29.2	28.1	28.1	23.4	NA	NA
Totals	29.2	36.6	37.4	35.5	18.9 + $20 k/yr	25.1 + $20 k/yr

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[a] Values include a 25% contingency and are in constant 1978 dollars.

[b] Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and include cost of deep geologic disposal of dismantled, highly activated components.

[c] NA-Not applicable for this decommissioning alternative.

TABLE 13.3-4. Estimated Costs of Decommissioning Each ISFSI in a Nuclear Energy Center ($ Millions)[(a)]

Item	DECON	SAFSTOR 10 Years	SAFSTOR 30 Years	SAFSTOR 100 Years	ENTOMB
Entombment	NA[(c)]	NA	NA	NA	3.0
Safe Storage Preparation	NA	1.9	1.9	1.9	NA
Continuing Care	NA	0.5	1.4	4.6	NA
Decontamination	4.3	3.7	3.7	3.7	NA
Totals	4.3	6.1	7.0	10.2	3.0[(b)]

[(a)] Values include a 25% contingency and are in constant 1978 dollars.

[(b)] Does not include the cost of surveillance and maintenance. While the center is operational, this cost is small. However, this cost could continue in perpetuity at an annual cost of $45,000.

[(c)] NA-Not applicable for this decommissioning alternative.

similar. The cost of DECON for each PWR is reduced from $33.3 million at dispersed sites to $29.2 million at a nuclear energy center, and the cost of DECON for each ISFSI is reduced from $4.6 million to $4.3 million.

13.3.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a reactor in such condition that the risk to safety is within acceptable bounds, and that the facility can be stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

In the case of the nuclear energy center, 30-year SAFSTOR (safe storage of 30 years followed by deferred decontamination) offers the advantage that reactor 1 would be ready for deferred decontamination (Figure 13.1-1) at the 80th year, just as construction on reactor 36 is completed. Since the construction crew would no longer be needed for construction (reactors 37, 38, 39, and 40 are under construction with other crews), part of it would become available for deferred decontamination of reactor 1, thus preserving the expertise of the crew. Operating crews of reactors 17 through 36 would also be available for consultation. Thus, deferred decontamination could be carried out sequentially just as construction is, with no break between construction of the last reactor and deferred decontamination of the first. If decontamination takes 4 years and construction takes 10, then portions of two of the five construction crews could conveniently be made available for deferred decontamination activities.

Occupational radiation dose from reactor decommissioning would be reduced because of reduced transportation distance to waste disposal sites. The total dose reduction would be from 329 man-rem for a single site to 318 man-rem for a nuclear energy center for a 30-year SAFSTOR (Table 13.3-1). Public radiation dose from reactor decommissioning would be reduced from 3 man-rem to essentially zero for a 30-year SAFSTOR because the waste transportation activities all take place onsite. There would be no reduction in either public or occupational radiation doses from decommissioning the ISFSIs, because transportation related doses are already essentially zero (see Section 12).

Costs of 30-year SAFSTOR for a PWR would be reduced from $42.8 million for a single site to $37.4 million for a nuclear energy center because of planning, transportation, and surveillance cost savings (Table 13.3-3). Similar savings would reduce the cost of 30-year SAFSTOR of the ISFSI from $7.3 million to $7.0 million (Table 13.3-4).

13.3.3 ENTOMB

ENTOMB is the complete isolation of radioactivity from the environment by means of massive concrete barriers until the radioactivity has decayed to levels which permit release of the facility for unrestricted use. ENTOMB is a possible, although relatively unattractive decommissioning alternative for a nuclear energy center. While the initial cost of entombment per reactor may be only one-half that of the total cost of 30-year SAFSTOR, the radiation dose may be more than twice as much. Also, surveillance and maintenance costs of $20,000 per year would continue in perpetuity, since as discussed in Section 4.3.3 the entombed structure would contain very long-lived radionuclides.

Although two ENTOMB alternatives are possible (see Section 4), only the case of reactor internals removed (and disposed of onsite) offers the possibility of radionuclides in the facility decaying to levels permitting unrestricted use of the facility within a reasonable time, i.e., the order of 100 years. Occupational radiation dose per reactor with internals included is 900 man-rem (Table 13.3-1). Occupational radiation dose per reactor with internals removed is 1000 man-rem. Radiation dose to the public would be reduced to near zero in either case because transportation of radioactive wastes is confined to the site. The radiation dose to workers (15 man-rem) and to the public (negligible) from decommissioning the ISFSIs would not change.

The cost of PWR ENTOMB with internals included would be reduced from $21.0 million for a single site to $18.9 million, for a nuclear energy center, and the cost of PWR ENTOMB with internals removed would be reduced from $27.0 million to $25.1 million. The cost of continuing surveillance during ENTOMB would be reduced from $40,000 per year to $20,000 per year (Table 13.3-3). The cost of ISFSI ENTOMB would be reduced from $3.25 million to $3.05 million (Table 13.3-4). The cost for ISFSI surveillance and maintenance during ENTOMB which could continue in perpetuity ($46,000 per year) may be somewhat reduced while other facilities onsite are also under surveillance. ENTOMB (without internals) for reactors has some viability because of long-term continued presence onsite of surveillance crews. However, as indicated in Section 4.3.3, adequate characterization of radionuclide content for license termination may be difficult.

13.4 ENVIRONMENTAL CONSEQUENCES

Because handling of all radioactive materials is carried on within the boundaries of the nuclear energy center, radiological impacts on the public will be much less than for a single reactor site. There will be no highway-related radiological impacts. In fact, there will be no highway-related impacts of any kind, except for bringing decommissioning workers and materials to the center. Releases to water will be negligible, as in the case of facilities on dispersed sites. The impacts on the public of releases of radioactivity to the air will be less than in the case of dispersed sites. This is because the public will be, on the average, farther away from each reactor because of the large area of the nuclear energy center.

Radiological impacts on transportation workers will also be less because transportation of wastes is confined to the center. The possibility is excellent that radiation dose to decommissioning workers can be reduced because of the experience gained from the repetition of the decommissioning process.

Although waste disposal will include the dedication of approximately 1 km^2 (250 acres) of radioactive waste burial grounds (20% of which is estimated as due to decommissioning waste), it is assumed that appropriate control of inventory and site will allow for unrestricted release in several hundred years for shallow-land burial.(7) Waste conditions that would require longer time periods to achieve unrestricted release are assumed to be placed in appropriate deep or intermediate depth geologic burial grounds available on site.

A major socio-economic impact will occur at the time construction of the last reactor is completed. If DECON has been chosen, decommissioning crews will already be onsite and the five construction crews will be discharged at 2-year intervals over an 8-year period. If, on the other hand, 30-year SAFSTOR has been chosen, then small portions of two construction crews may be kept on to carry out deferred decontamination of the reactors. At the end of decontamination of the reactors only a surveillance crew will be required because of the waste buried onsite. With the choice of 30-year SAFSTOR, the 40-reactor nuclear energy center offers the possibility of 162 years of managed growth, relative stability, and orderly phaseout.

13.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

For a reactors at nuclear energy centers, 30-year SAFSTOR is probably a more acceptable alternative than for a single reactor facility. DECON and ENTOMB (with internals removed) are also possible alternatives at higher radiation dose and lower cost; the more likely alternative being DECON. Surveillance would, of course, have to be maintained in the case of ENTOMB.

REFERENCES

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6. "Report to the President by the Interagency Review Group on Nuclear Waste Management," TID-29442, March 1979.

7. E.S. Murphy and G.M. Holter, *Technology, Safety and Costs of Decommissioning a Low-Level Waste Burial Ground*, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, NUREG/CR-0570, May, 1980.**

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*Available for purchase from the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC, and the National Technical Information Service.

14.0 NON-FUEL-CYCLE NUCLEAR FACILITIES

Non-fuel-cycle facilities are those facilities which handle byproduct, source and/or special nuclear materials but which are not involved in the production of power as outlined in Figure 2.1-1 of Section 2 of this EIS. These non-fuel-cycle facilities must be licensed by the NRC or the Agreement States.

There are thousands of non-fuel-cycle facilities in the United States at which byproduct, source and special nuclear materials are handled under specific licenses of the NRC and the agreement states. These facilities house operations that vary from the occasional use of a few short-lived radionuclides by a doctor to the large scale processing of radioactive materials (gaseous, liquid, and particulate forms). The operations include a wide range of applications in industry, medicine, and research such as manufacture of smoke detectors, radiation therapy equipment, and manufacturing quality control instruments.

Tables 14.0-1 and 14.0-2 give the number of NRC specific material licenses and of agreement state licenses, respectively. Approximate numbers of those which are not connected with the fuel cycle are given in parentheses in Table 14.0-1. These numbers do not exactly represent the number of existing facilities since some of the commercial establishments are licensed under more than one part of the regulations and thus have more than one license.

A large majority of the non-fuel-cycle material licensees have facilities which do not require a major decommissioning effort. However, a few of the non-fuel-cycle facilities will require significant decommissioning procedures which may present some unique problems and which may have rather large decommissioning costs and significant environmental impacts. A detailed technical report on the decommissioning of non-fuel-cycle nuclear facilities,(1) similar to those prepared for other facilities discussed in this EIS, is planned for issuance in fiscal year 1981. Information in this section is based on preliminary information from that report and therefore, the cost and dose estimates given here are also preliminary. For the purposes of presenting representative information in this EIS, a few reference facilities have been selected which are considered to involve significant decommissioning activities. These facilities are: manufacturers of sealed sources, manufacturers of radiochemicals, research and development institutions, and processors of ores in which the tailings contain licensable quantities of radionuclides. Some preliminary estimates of the costs and radiological impacts of decommissioning these facilities are presented.

14.1 FACILITIES DESCRIPTION

Brief descriptions of the selected types of non-fuel-cycle nuclear facilities are given in the following subsections. A reference facility has been selected for each type of operation in order to facilitate estimates of costs and radiation doses due to decommissioning.

14.1.1 Sealed Source Manufacturer

Sealed sources are manufactured for such uses as reference standards, moisture probes, quality control instruments, therapy units, and smoke detectors. In general, these uses require long-lived isotopes, but fairly

TABLE 14.0-1. NRC Material Licenses as of June 1978

Byproduct			
Medical	2 239		
Academic	384		
Industrial	4 205		
Civil Defense	104		
Other	27		
Total Byproduct		6 959	(6 924)[a]
Source		400	(332)
Special Nuclear		720	(583)
Total		8 079	(7 839)

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[a] Licenses not connected with the nuclear fuel cycle are in parenthesis. These numbers were obtained by subtracting fuel cycle facilities and also export/import licenses which are, in effect, paper transactions and do not represent separate facilities.

TABLE 14.0-2. Agreement State Licenses (June 1978)

Medical	4 749
Academic	867
Industrial	5 030
Civil Defense	185
Other	900
Total	11 731

weak sources, except for ^{60}Co therapy units in which high-energy, high-intensity gamma ray emission is the most important consideration. The manufacturing process is a hand operation that does not lend itself to mass production. Alpha and beta emitters are plated on platinum, stainless steel, or alumnized mylar film and mounted in aluminum rings to form standard disc sources. Liquid gamma sources are sealed in plastic or glass vials, and solid gamma sources are mounted in rods or plastic discs.(2) The materials are handled in hoods, glove boxes, or hot cells, depending on the kind and energy of emissions (exposure potential of the isotope).

Contaminated glassware and equipment that cannot be economically reclaimed are discarded into drums for shipment to a waste burial ground. Spills are cleaned up when they occur, and the area and equipment are monitored regularly. Ventilation systems utilize absolute filters, and contamination is thus generally confined to the interiors of the hoods, glove boxes or cells, and the ducts and filters.

The reference facility for sealed source production is New England Nuclear Corporation (NEN) of Boston, Massachusetts. NEN has manufacturing facilities at both Boston and Billerica, Massachusetts. These buildings contain a number of small laboratories, each of which is devoted to a specific process and/or isotope. Each laboratory contains one or more hoods, glove boxes, and/or hot cells. People entering the laboratory areas change shoes or put covers over their shoes; when exiting, they change again and monitor their hands and shoes for radioactivity.

Radioactive wastes are placed in drums and stored in separate buildings until shipped to a waste burial ground or, in the case of short-lived isotopes like ^{32}P, the drums are held on the premises until the isotope has decayed to a suitable level of activity.

14.1.2 Radiochemical and Radiopharmaceutical Manufacturers

Manufacturing facilities for radioactively labeled chemicals and pharmaceuticals are much the same as those for the manufacture of sealed sources in that operations are carried out in ventilated enclosures. Chemical manufacturing, however, requires more extensive and complicated laboratory equipment to perform the inorganic reactions and organic syntheses. The isotopes are either shipped in from an outside supplier or are produced in onsite cyclotrons.

The reference facility for the manufacturing of labeled chemicals is also New England Nuclear Corp. Chemical syntheses are carried out at both their Boston and Billerica plants. The physical facilities for these operations are the same as those for sealed source manufacturing.

Syntheses are performed in small batches in hoods, glove boxes, or hot cells equipped with absolute filters. Each chemical is produced in a separate laboratory, which is a restricted area. There are a maximum of 30 laboratories with penetrating radiation. No external dose is received in the other laboratories. As compounds progress through their synthesis, they are moved from hood to hood through connecting doors and are packaged in lead shipping containers before being removed from the hood. Radioactive solid waste, including glassware, is placed in plastic-lined drums for disposal. Before being removed from the restricted area, liquid wastes are put in leakproof, shatterproof containers filled with absorbent materials and are labeled as to quantity, type of activity, date, and surface dose rate.

All wastes are placed in drums and moved to a separate building where the short-lived isotopes, such as ^{32}P, are allowed to decay to negligible levels. Wastes with long-lived isotopes are shipped to waste burial grounds.

14.1.3 Ore Processors

Non-fuel-cycle processing facilities that deal with ores containing appreciable concentrations of radionuclides are licensed to store their mill tailings. There are relatively few such facilities in the U.S., but the volumes of tailings they generate are sufficient to require a significant decommissioning effort.

The reference facility is the Kawecki Berylco Industries plant at Boyertown, Pennsylvania, a subsidiary of the Cabot Corporation. The site consists of a storage area for drums of ore, an administrative and laboratory building, two processing buildings, and three connected buildings for storage of ore tailings. The ore consists of slag which is produced by tin smelters located on the Malay Peninsula. In one building of the reference facility, the slag is ground, roasted, and then digested with hydrofluoric acid. The hydrofluoric acid is filtered off and passed to the other building for extraction of tantalum and niobium. The remaining sludge contains uranium and thorium at concentrations similar to many of the uranium ores being mined in the U.S. The tailings are removed as a fairly dry filter cake and stored in bulk in aboveground buildings constructed for this purpose. These are concrete buildings with slab floors and prestressed concrete roofs. The gables are left open to prevent a buildup of radon. Presently the amount of stored sludge is on the order of 12×10^6 pounds (5.4×10^6 kg). At a similar plant in Oklahoma, the tailings are sluiced to lined tailings ponds, where the water is allowed to evaporate.

In such a facility, the radioactivity is primarily in the tailings; nowhere else in the operation is there significant contamination. The operational problem is that there is currently no satisfactory place to ship the tailings for disposal. Storage in specially made aboveground structures becomes expensive and cumbersome, and in addition, the operating license may limit the amount of tailings that can be stored onsite.

14.1.4 Broad Research and Development (R&D) Program Facility

R&D facilities using nuclear materials cover an extremely broad range of activities. For the purpose of this discussion, a large university is assumed to be representative of many of these R&D activities. The reference university is the University of Washington in Seattle, Washington. There are about 400 laboratories or health treatment areas on the university campus that have used or are using radioisotopes. Radioisotopes are used in chemistry and physics laboratories to conduct basic experiments and in biological laboratories to investigate absorption and metabolic phenomena. These laboratories, in general, present no decommissioning problems because the isotopes used are short-lived and are of low activity. The university also uses radioisotopes for various medical purposes in a university hospital and a health services complex. These uses include both radiation exposure from sealed sources and injections of short-lived isotopes. Most of these isotopes are produced elsewhere, but ^{99}Tc is produced from ^{99}Mo in a technetium generator.

Probably the highest intensity source used is the sealed ^{60}Co source used in biological irradiation studies of fish. This source is on the order of 40,000 Ci, so shielding requirements are extensive, and these shielding requirements must be considered in decommissioning activities.

The longest lived isotopes normally used are ^{3}H and ^{14}C, both of which are low-energy beta-emitting isotopes. Other isotopes that are commonly used as tracers include ^{125}I, ^{55}Fe, ^{36}Cl, ^{26}Al, ^{55}Cr, and ^{35}S. Radioactive wastes are packaged for shipment to a waste burial ground.

14.2 NON-FUEL-CYCLE MATERIALS FACILITIES DECOMMISSIONING EXPERIENCE

Decommissionings of non-fuel-cycle facilities have been many and varied, and a large number of these operations have had little cost or environmental impact. Because of their unique sizes, locations, and conditions, no two facilities had identical decommissioning problems or conditions. Documentation on these decommissionings is fragmentary. However, a number of things, as discussed below, are apparent from the documentation that is available on the decommissioning of these facilities.

First, a large variety of facilities, both commercial and others, have been successfully decommissioned without unreasonable occupational exposures or significant public exposures. The decommissioning approach has generally been to decontaminate the facility to radioactivity levels low enough to permit release of the facility for unrestricted use.

Each facility can present problems that are unique to its decommissioning. In some cases, these problems can lead to uncertainties in estimating costs for decommissioning, even at the time of shutdown. This is particularly true for a facility where a number of operations involving processing of a variety of nuclides have been carried out and an adequate history of operations and events has not been documented. However, what is also apparent is that the same basic approach to decommissioning applies to all facilities and that knowledge obtained from experience in decommissioning, in general, including some methods of facilitation, can be applied as appropriate to any facility.

There has also been some decommissioning experience specifically relevant to the types of facilities chosen as references. Manufacturers of sealed sources and labeled chemicals carry out their operations in small batches in glove boxes, hoods, or remote operation cells, and contamination outside these structures is limited almost entirely to the ventilation ducts and filters. The isotopes creating the worst problems in these facilities are ^{14}C, which requires tedious inspection and cleanup; ^{3}H, which is easily dispersed and requires many washes to remove; and gases of [illegible], ^{131}I, and ^{85}Kr. Equipment for handling cesium and strontium becomes so thoroughly contaminated that it is buried without any attempt to clean it up.

New England Nuclear Corp. has had a great deal of experience with these kinds of structures and has decommissioned an entire five-story building plus basement, that is now being put to other, non-nuclear uses. Decommissioning criteria used by NEN are given in Ref. 3. This decommissioning consisted of removing all the isotope-handling equipment and ventilation ducts, decontaminating them when possible, and if not economically recoverable, disposing of them to low-level waste burial grounds. In practically all cases, it was not considered economically feasible to decontaminate ductwork. The entire facility was surveyed for radioactivity and any areas with contamination levels of 900 or more dpm per 100 cm^2 were cleaned to reduce contamination by at least a factor of 2. The walls and ceilings were steam cleaned. The floors consisted of vinyl tile laid over plywood on top of the original floor. Where contamination occurred, the floor tiles were replaced and, if necessary, sections of the plywood were cut out and replaced. Some of the worst areas of contamination were under the laboratory benches, which were not accessible for routine cleaning. Glove boxes that were not to be reclaimed were spray painted, loaded with contaminated equipment, filled with a quicksetting foam material, and shipped to a low-level waste burial ground. Lead bricks were etched with HCl, and areas contaminated with ^{14}C were washed with NaOH and NH_4OH. These same procedures are followed on a continuing basis as NEN rearranges and remodels other laboratories.

Experience with decommissioning of commercial non-fuel-cycle ore processing facilities is limited, primarily because there are few such facilities in the U.S. The ores handled in these facilities have such low levels of radioactivity that the machinery can be readily decontaminated and surveyed to confirm that radioactivity levels are low enough to allow unrestricted use. Therefore, the main problems with decommissioning are disposal of the slag or tailings and cleaning up of spills. Kawecki Berylco Industries, Inc. has one such site in which the contaminated surface soil was scraped into a single pile and stabilized with vegetation. The matter of final disposition of the sludge from current operations containing the unextracted uranium and thorium has not been solved.

Also relevant to the decommissioning of this type of facility is the ongoing work to decontaminate some sites which had been used some time ago for similar processes and subsequently abandoned. Two of these are: Reed Keppler Park in West Chicago, where thorium-containing wastes from a rare earth processing plant had been deposited in the 1940s, and a plant in Parkersburg, West Virginia, where ore had been processed for the recovery of zirconium and hafnium.

Experience in dealing with uranium mill tailings piles is also relevant to decommissioning this type of operation since they present similar problems.

14.3 DECOMMISSIONING ALTERNATIVES

Decommissioning alternatives likely to be used for non-fuel-cycle materials facilities are discussed in the following subsections, first as they apply in general and then as applied specifically to the reference facilities. The general section describes each of the alternatives presented in Secton 2.4 for non-fuel-cycle facilities. The specific section for each reference facility discusses only those alternatives considered viable for that facility.

14.3.1 Decommissioning Alternatives for Non-Fuel Cycle Facilities

Once a non-fuel-cycle facility has reached the end of its useful operating life it must be decommissioned. As discussed in Section 2.3, this means safely removing the facility from service and disposing of all radioactive materials in excess of levels which would permit unrestricted use of the facility. Several alternative are considered here as to their potential for satisfying this general requirement for decommissioning. The decommissioning alternatives considered and discussed here are DECON, SAFSTOR, and ENTOMB.

Since there is such a large range in the type and size of facilities and operations licensed to handle radioactive materials, the level of effort required to decommission these facilities varies greatly. The necessary actions can vary from essentially administrative procedures for small facilities (in addition to a final certification survey which could be similar to operational surveys) to a multi-million dollar effort for the more significantly contaminated facilities. For many materials handling facilities it may be quite straightforward to determine what actions are necessary; for some, however, detailed consideration of more than one viable alternative may be required. Any of the decommissioning alternatives listed above may be viable for some of the non-fuel-cycle facilities. For a large number of non-fuel-cycle facilities some variation or combination of these alternatives will be the best choice. The same kind of security measures as were employed during operation, but at a lower level, will be required during decommissioning. Discussion of the decommissioning alternatives follow.

14.3.1.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of DECON procedures. The end result is the release of the site and any remaining structures for unrestricted use. A large number of non-fuel-cycle facilities will require some positive action in order to reduce radioactivity to levels considered acceptable for releasing the facility for unrestricted use. The procedures necessary for DECON vary greatly with the type of facility and its operation. Any procedure, whether involving only removal of sealed sources, decontamination, or actual dismantling, will follow the general concepts defined for DECON in Section 2.4.2. DECON can include dismantling, removing, and disposing of any contaminated equipment, as well as decontaminating or removing any contaminated parts of the building.

For many non-fuel-cycle facilities, the most appropriate decommissioning alternative will be DECON. This will involve decontamination of the facility, but most licensees will not need to dismantle the facility.

In the case of an ore processing facility, removal of slag also follows the general concept of DECON. An extension of this option is chemical extraction of the radionuclides, in which case the depleted sludge can be disposed of in a landfill and the radionuclides taken to a waste burial site or sold.

14.3.1.2 SAFSTOR

SAFSTOR is defined as those activities required to place (preparation for safe storage) and maintain (safe storage) a non-fuel-cycle facility in such condition that the risk to safety is within acceptable bounds, and that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination).

For some of the materials facilities, SAFSTOR may be an acceptable and desirable decommissioning alternative. The simplist case illustrating the advantage of SAFSTOR would most likely be if most or all of the radioactivity in a specific facility is from relatively short-lived nuclides that will decay to levels permitting unrestricted use of the facility in a short time. In this case, little action, in some cases just a radiation survey, is expected to be required at the time of deferred decontamination. During the safe storage period, the facility would have to be made secure against intrusion. Limited surveillance and monitoring would also be required.

Stabilization may be a decommissioning alternative considered for the slag remaining at ore processing facilities. At this time, the NRC has not determined whether this will be acceptable; but currently its acceptability would be considered on a case-by-case basis. Stabilization of slag piles would be considered as preparation for safe storage and would require monitoring until final disposition.

14.3.1.3 ENTOMB

ENTOMB requires the encasement of a facility in concrete to protect the public from radiation exposure until its radioactivity has decayed to levels permitting unrestricted use of the facility. For a non-fuel-cycle facility, ENTOMB would require the construction of a heavily reinforced concrete building in advance of licensing in which the facility operations would be conducted. Given the expense of construction and the low radioactivity level of most of the isotopes to be handled, ENTOMB does not appear to be a viable alternative.

14.3.2 Decommissioning Alternatives for Sealed Source and Radiochemical Manufacturers

The same kinds of facilities are used in the manufacture of sealed sources and radio-labeled chemicals. Since the methods for decommissioning these facilities are the same, they are combined in this discussion. The alternatives considered for decommissioning these facilities are DECON and SAFSTOR. These are discussed below.

14.3.2.1 DECON

DECON is a logical alternative for facilities such as those of New England Nuclear Corp. which have been established for the manufacture of sealed sources and radio-labeled chemicals. It is relatively uncomplicated, will eliminate a need for continued monitoring, and will release the facility for other uses.

Decontamination activities will include the removal of hoods, glove boxes, hot cells, laboratory benches, and ventilation systems. Room surfaces will be washed and floor coverings removed as needed to eliminate hot spots that may have resulted from spills.

In planning a decommissioning action, it is important to know the history of the operation, how diligent the operators were in keeping the rules regarding contamination and releases, and how good a record of accidents and spills was kept.

Methods of disposal of equipment will depend on what isotopes are involved and on future use of the equipment. Hoods that have been used for strontium and cesium may be so badly contaminated that they cannot be reasonably and economically cleaned for further use. These will be shipped to low-level waste burial. Other hoods may be decontaminated to a suitable radioactivity level for reuse in a nuclear facility by removing the baffle and washing the hood surfaces, or, if they are easily decontaminated or have been used with short-lived isotopes, they may be cleaned and made suitable for unrestricted use. It may be economically attractive to decontaminate stainless steel equipment by electropolishing.

Hoods that are to be discarded as low-level waste will be painted to seal in the radioactivity, filled with other contaminated equipment, such as ductwork and filter boxes, and packaged in plywood boxes for shipping to a burial ground. Glove boxes will be filled with a quicksetting foam material, packaged, and shipped to a burial ground. Hot cells and manipulators will be disassembled and compressed into steel drums. The actual handling and disposal methods will depend on the quantity of activity and the radiation characteristics. These methods will also determine the number of barrels needed for packaging, which in turn will greatly influence the disposal cost. An estimate of costs and manpower requirements for decommissioning various components of this kind of facility is shown in Table 14.3-1. Decisions on the extent of dismantling and on discarding specific items will depend on the dollar value of the item and the cost and degree of difficulty of decontaminating it. These will be case-by-case decisions.

TABLE 14.3-1. Estimate of Manpower Requirements and Costs of Decommissioning the Laboratories of a Sealed Source or Radiochemical Manufacturing Facility

1. Simple decommissioning. Laboratory area 20 x 20 ft with low-level contamination used for amino acid syntheses. Clean only.

Action	Man-Days Required	Materials	Rounded Cost
Supervision	6		$1 010
Wash down and wipe	10	$1 000	2 040
Monitoring	2		280
Reclean hot spots	2		210
Total Cost			$3 540

2. Intermediate decommissioning. Beta or research lab area 25 x 25 ft with four 12-ft benches, four 5-ft hoods, 1 sink.

Action	Man-Days Required	Materials	Cost
Supervision	10		$1 685
Dismantle hoods (technicians)	8		830
Remove plumbing (plumbers)	2		208
Remove filter system (sheet-metal workers)	2		208
Monitor	4		550
Package waste (10 drums;	3	$ 500	815
Haul and bury waste (800 miles)			1 126
Wash down and wipe	5	1 000	1 520
Total Cost			$6 942

3. Difficult decommissioning. Gamma lab similar to a beta lab but with a hot cell, 4 x 4 x 4 ft with overhead manipulators.

Action	Man-Days Required	Materials	Cost
Supervision	12		$2 020
Dismantle hoods (technicians)	8		830
Remove plumbing (plumbers)	4		415
Remove filter system (sheet-metal workers)	4		415
Dismantle hot cell	5		520
Monitor	8		1 108
Package waste (15 drums)		$ 750	4 600
Certify drums for shipment			1 450
Haul and bury waste (800 miles)			1 300
Wash down and wipe	5	1 000	1 520
Total Cost			$14 178

Actual packaging and shipping costs will depend on the isotope involved. Iodine hoods, for example, may be decontaminated by wiping, but all the wastes have to be placed in packages that are surrounded by activated charcoal in a steel drum.

Decommissioning workers will wear respirators and protective clothing to protect against dust, so external exposure will be the principal exposure pathway. The levels of exposure will depend on the isotopes processed in a particular laboratory. At the reference facility, waste barrels are packed to measure no more than 250 mR/hr on the surface, or, if the waste has very high radioactivity level, the barrel is kept to no more than 5 R/hr and it is kept shielded during handling and loading. Exposure of decommissioning workers is generally kept within operational exposure levels, and in no case is a worker allowed to receive more than 300 mrem/week.(4)

The critical exposure time in decommissioning a laboratory is during the removal of the hoods, ventilation system, and hot cell. During this time, external exposure can be as high as 100 mrem/week. The remainder of the decommissioning time is spent in scrubbing hot spots. During this time, dose levels are at or below those encountered in operation of the laboratory (about 3 mrem/day). If there are 30 laboratories with hot cells involved which have these radiation levels, the total worker dose from external radiation will be about 15 man-rem.

14.3.2.2. SAFSTOR

SAFSTOR is a reasonable alternative for decommissioning if the isotopes involved at a particular facility are short-lived and the facility has no other immediate planned usage. Use of a safe storage period of a few days to a few months may allow the radioactivity to decay to low enough levels that no further decontamination is required and that little action, perhaps only a radiation survey and some administrative action is necessary for releasing the facility for unrestricted use.

14.3.3 Decommissioning Alternatives for Processors of Radioactive Ore

The milling of nonradioactive metals by Kawecki Berylco Industries from ores containing uranium and thorium will contaminate the handling or milling equipment where the materials are retained by machinery. A simple survey and cleanup is the only decommissioning action required. As the materials are processed, all of the uranium and thorium remain with the sludge from the initial extraction, and the following decommissioning alternatives are considered for the sludges: removal (DECON), and neutralization and stabilization for long-term care.

14.3.3.1 Removal (DECON)

A potential decommissioning alternative is removal of the sludge from the milling site and disposal of it at a low-level waste burial ground. The effectiveness of this action could be enhanced by mixing lime into the sludge to neutralize any acid in it before depositing it where it might be contacted by water. Drawbacks to this option are the great amount of material that must be handled for the sake of a relatively small amount of radioactivity and the long distances that the material must be transported. Costs to transport and dispose of the sludge at a low-level waste burial ground 1500 miles away, assuming that there are 20 million pounds of sludge, will be approximately $2.9 million (Table 14.3-2). The costs for transporting and burial are the major costs of disposal.

Radiation exposure to workers handling this sludge will be very similar to that of people working with uranium mill tailings piles. Radiation levels are 0.5 to 1.0 mrem per hour. Wearing respirators will reduce any problems from inhalation of particulates and leave only ^{222}Rn as a concern. Radon levels at the sludge site are also similar to levels at a tailings pile. Exposures and dose estimates to the workers and public are shown in Table 14.3-3.

TABLE 14.3-2. Approximate Costs for Disposal of 20×10^6 Pounds of Sludge

Removal	
Loading	\$ 50 000
Hauling (at \$100,500/10^6 lb)	2 010 000
Burying (at \$0.04/lb)	800 000
Monitoring and Certification	4 500
Total	\$2 864 500
Stabilization	
Equipment and Materials	\$ 41 000
Labor	39 000
Total	\$ 80 000

TABLE 14.3-3. Exposures and Dose Estimates of Public and of Workers Removing or Stabilizing a Reference Ore Sludge Pile

	Stabilize in Place (man-rem)[a,b]	Remove to Burial Ground (man-rem/10^6 lb)[b]
Occupational dose		
External	0.2	1
Internal		
Bronchial epithelium	4×10^{-3}	1×10^{-4}
Pulmonary lung	1×10^{-3}	3×10^{-5}
Bone	1×10^{-3}	3×10^{-5}
Population dose		
External	0	2×10^{-2}
Internal		
Bronchial epithelium	3×10^{-6}	1×10^{-7}
Pulmonary lung	7×10^{-7}	3×10^{-7}
Bone	6×10^{-7}	2×10^{-7}

(a) Assumes 20×10^6 lb of sludge occupying a volume of about 40 m x 40 m x 4 m high.

(b) Values adapted from calculations made by PNL as input to the technical report indicated in Section 14.0; based on analysis of actual sludge.

This sludge could be disposed of in a local landfill if it did not exceed an acceptible residual radioactivity dose limit, which has yet to be determined.

Decontamination of the sludge by chemical removal of the uranium and thorium seems an attractive alternative, especially if the extraction costs are low enough that sale of the recovered uranium would return a profit or at least reduce the net cost of disposal. Previous milling practices may have affected the chemical nature of the uranium and thorium so that conventional milling methods will be ineffective. Any extraction process would have to remove thorium as well as uranium to make the sludge acceptable at a landfill.

14.3.3.2 Neutralization and Stabilization

This alternative is similar to preparation for safe storage and is followed by long-term care. The steps to accomplish this are to remove the roof, cover the pile with lime to neutralize residual acid, cover the entire structure with backfill, add a clay cap, cover with topsoil, and plant vegetation. The requirements for the kind and depth of cover will be similar to that for uranium tailings piles. However, while uranium mills and their tailings piles are generally located in the semi-arid western part of the U.S., the ore processing plants are likely to be found in areas where humidity and rainfall are much higher and the water table shallower. This will likely increase the need for protection against erosion, but vegetation to stabilize the surface will also grow better in this moister climate. This alternative may not be viable over a long term and would have to be considered on a case-by-case basis. Cost and radiation dose estimates for this alternative are shown in Tables 14.3-2 and 14.3-3, respectively.

14.3.4 Decommissioning Alternatives for Broad Research and Development Program Facilities

Decommissioning a large R&D facility is a piecemeal operation because of the many separate working areas involved, although each area is relatively uncomplicated. The major activity in preparation for decommissioning will be the elimination of inventory. An accurate accountability system is difficult where such a large variety of laboratories and uses is involved, as at the University of Washington. Some laboratories may have small amounts of ^{14}C compounds, for example, left over from experiments conducted several years previously. Preparation for decommissioning must include an exhaustive inventory to discover these. The elimination of any inventory is the next step of decommissioning, which is carried out before the rest of the facility is decommissioned. The decommissioning alternatives considered are: DECON and SAFSTOR. These are discussed below.

14.3.4.1 DECON

A viable alternative for decommissioning an R&D laboratory is DECON. For many of the laboratories, this will not require discarding equipment. Most hoods, glove boxes, and ventilation systems can be decontaminated by washing. For laboratories where long-lived isotopes (^{3}H and ^{14}C) have been used over a period of several years, it may be sufficient to wash and paint the exposed surfaces or it may be desirable to discard some of the equipment as low-level waste. If they are to be discarded, the hoods and glove boxes will be painted to stabilize the surface contamination before dismantling. Ducts and other ventilation equipment parts will be placed inside the hoods and packaged for disposal at a low-level burial site.

Because cleanup activity is slight, the greatest decommissioning cost is expected to be the survey. A laboratory will require about 1 man-day for a complete survey. Any surface contamination found should be removable to an acceptible residual activity level by washing. If it is found necessary to disassemble equipment to wash hidden surfaces, this could prove more time-consuming than the survey.

The rooms in which the laboratories are located will not require decontamination unless there are spots where spills were inadequately cleaned up. Even then, cleanup will be necessary only where long-lived isotopes are the contaminant as shown by survey.

Of the 400 laboratories using radioisotopes at the reference facility, perhaps 20 have enough contamination to give an external dose of 1 mrem/hr. If it takes two days for three people to decontaminate a laboratory, the total dose to decommission all laboratories will be about one man-rem.

14.3.4.2 SAFSTOR

For most of the laboratories at an R&D facility, this is the decommissioning alternative most likely to be employed. Except for ^{3}H and ^{14}C, the isotopes used at such a facility have short half-lives and a wait of a few days to a few months will allow the radioactivity to decay so that no further cleaning or dismantling is necessary. SAFSTOR assumes either that a laboratory can be left unoccupied for a time or that a survey indicates that the kinds and/or levels of radiation will permit people to work safely in the laboratory. The total cost of decommissioning will be that for extensive surveys to monitor decay of the radioactivity. This option will not apply to laboratories with long-lived isotope contamination. For a laboratory that has handled only ^{3}H or ^{14}C, DECON is probably the more viable alternative since these isotopes will not decay for many years. If several isotopes have been used in this same facility, it may be desirable to let the short-lived ones decay before decontaminating. Personnel exposure under this option will be negligible.

14.4 ENVIRONMENTAL CONSEQUENCES

There are other possible environmental consequences from decommissioning these kinds of facilities that cannot be reasonably discussed on a generic basis but have to be assessed for individual facilities. These include the effects on a local work force and on a local economy. The greatest impacts of this type will have occurred when the operations ceased and the effects of decommissioning will be minor by comparison.

The greatest terrestrial disturbance will come from decommissioning an ore processing facility, because of the large quantity of material involved. The alternative of stabilizing the tailings will require a large amount of earthen fill, the obtaining of which will necessitate digging up another area. Both the stabilized site and the borrow area will likely require reclamation and monitoring to prevent problems with erosion and surface water sedimentation. Of great concern with these facilities will be potential chemical toxicity from the processing chemicals and mobilized heavy metals in the tailings.

Both occupational and public exposure to radioactivity will be small for decommissioning a single facility. Although there are a large number of facilities, the potential dose from decommissioning all of the facilities is still expected to be relatively small.

14.5 COMPARISON OF DECOMMISSIONING ALTERNATIVES

A comparison of decommissioning alternatives is highly specific for each kind of non-fuel-cycle facility. For most of the facilities that come under this designation, a removal of inventory will eliminate nearly all of the possibility of radiation exposure. The facilities discussed here are those that are perceived to have the greatest need for decommissioning action.

The most likely alternative for decommissioning most non-fuel-cycle facilities is DECON. In these facilities, radioactive contamination is low. Therefore, cleanup is not difficult. In some facilities, or parts of facilities where only short-lived isotopes have been used, delaying decontamination for a few weeks or months (SAFSTOR) may allow all the radioactivity to decay and eliminate the need for actual decontamination operations leaving only a final survey to be done. Facilities where chemicals and pharmaceuticals have been formulated will require extensive cleaning of the inside building surfaces after the equipment has been removed. ENTOMB is not a practical decommissioning alternative for any of the kinds of facilities discussed here.

Stabilization with long-term care may be a viable alternative for disposal of radioactive tailings from an ore processing facility. These tailings are similar to uranium mill tailings and should be subject to the same requirements for stabilizing in place in comparable settings. The disposition of radioactive ore tailings (other than stabilization) has limited possibilities. Removal of the tailings to a low-level waste burial ground will be expensive but is feasible. Reprocessing to remove the radioactive elements from the sludge lacks practicality, mainly because the volumes and rates of production are not attractive to commercial processors.

Although, there are thousands of non-fuel-cycle nuclear facilities and the reference facilities discussed here have significant costs and impacts, the overall impact of decommissioning non-fuel-cycle facilities is not unreasonable. The reference facilities represent only a very few existing facilities which are comparable in size of operation, while for the large majority of the remaining facilities the impacts are small or non-existent. For example, approximately half of all the licensees are users of sealed sources and the environmental impacts of decommissioning these facilities are negligible. Also, most medical licensees (about 35% of all licensees) are for use of short-lived isotopes (and sealed sources), and the environmental impacts of these decommissionings would in most cases be very small. Hence, because most facilities have small environmental impacts due to decommissioning, the cumulative impact of decommissioning all of them is not significant.

REFERENCES

1. Technology, Safety, and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities, Prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, NUREG/CR-1754, to be published.

2. New England Nuclear Radioisotope Catalog, New England Nuclear Corporation, Boston, MA.

3. Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material, U.S. Nuclear Regulatory Commission, November 1976.

4. Handbook of Radiation Protection, Required Rules and Procedures, New England Nuclear Corporation, 1976.

15.0 NRC POLICY CONSIDERATIONS

At the end of the useful life of a commercial nuclear facility, prompt NRC (or agreement state) termination of a license is a desired objective. For such a facility, removal of the radioactivity down to levels which permit unrestricted use of the facility (including the site) through decommissioning is mandatory for full license termination. Present policy and regulatory guidance which addresses nuclear facility decommissioning is not specific enough in many areas required to adequately assure that this desired objective is accomplished in a manner consistent with protection of the public health and safety. Currently, the NRC has underway a plan for reevaluation of its decommissioning policy on nuclear facilities.(1) Addressed in this plan are commercial nuclear facilities that require decommissioning as part of their end of life operational period, including reactors and associated fuel cycle facilities, and non-fuel-cycle facilities. Decommissioning also includes the possibility of premature closure of a facility, where it becomes necessary to decommission the facility prior to the end of its planned life. Excluded from specific consideration in this plan are: (1) Shallow-land low-level waste burial, which is separately addressed in consideration of rulemaking activity in Title 10 of the Code of Federal Regulations, Part 61.(2); (2) Uranium mill and mill tailings, for which a Final EIS(3) is currently available and amended regulations have been promulgated; (3) High-level deep geologic burial grounds, which will be covered in separate rulemaking; (4) Uranium mines and currently existing government owned enrichment plants, which are not under NRC jurisdiction.

Decommissioning that occurs as a result of premature closure due to accidents may involve some technical and cost considerations not yet completely evaluated. A study to develop a data base on this subject for light-water-reactors will be initiated in fiscal year 1981, and a detailed report on decommissioning following a postulated accident, similar to those reports prepared for the facilities in this EIS, will be issued in fiscal year 1982. For other nuclear facilities, the study will begin in fiscal year 1982. While the basic purpose and objectives for decommissioning facilities involved in accidents would be the same as for routine decommissioning, some of the specific aspects of the technology, safety, and costs of decommissioning may differ. Nevertheless, in many instances even these specific aspects would have similarities between accident and routine decommissionings. In particular, (1) decommissioning alternatives and timing may be similar for accident and routine situations; (2) planning and facilitation for accident decommissioning would consider essentially the same topics as routine decommissioning, although activities, methods, and procedures probably would be different; (3) financial considerations would be similar since the licensee would still have the responsibility of funding decommissioning and financing for premature closure decommissioning is addressed in the EIS, however, costs for accident decommissioning are not currently known and other means for assuring funding may be needed for accident decommissioning; and (4) the recommended residual radioactivity level limits would still be expected to apply although the circumstances of the accident may require consideration of exceptions on an ALARA basis. It is not expected that major changes in the conclusions of this EIS will result from the technical studies on accident decommissioning, although there may be some differences in specific criteria. These items will be considered upon completion of the studies initiated in 1981 and 1982.

Consistent with the NRC plan for decommissioning policy reevaluation, a series of NUREG reports by Battelle Northwest Laboratory are being developed. Most of those NUREG reports are either completed or nearing completion.(1), (4)-(10) These reports are intended to serve as an information base for the development of decommissioning regulatory activities. In relation to such regulatory activities, an attempt has been made to maintain a dialogue with the States and the public during the early formative time of decisionmaking on critical issues.(1), (11), (12) Based on the nearly completed data base and on NRC staff considerations, taking account of the concerns of the States and public, and of the regulatory role NRC must provide in protecting public health and safety, the following conclusions appear evident:

(1) The technology for decommissioning nuclear facilities is well in hand and, while technical improvements in decommissioning techniques are to be expected, decommissioning at the present time can be performed safely and at reasonable cost. Radiation dose to the public due to decommissioning activities should be very small and be primarily due to transportation of decommissioning waste to waste burial grounds. Radiation dose to decommissioning workers should be a small fraction of their exposure experienced over the operating lifetime of the facility and usually be well within the occupational exposure limits imposed by regulatory requirements. Decommissioning costs are reasonable and are, at least for the larger facilities such as reactors, a small fraction of the present worth commissioning costs (i.e., less than 10%).

(2) Decommissioning of nuclear facilities is not an imminent health and safety problem. However, planning for decommissioning as an integral activity prior to commissioning is a critical item that can have an impact on health and safety as well as cost. Essential to such planning activity is the decommissioning alternative to be used and timing, as well as consideration of acceptable residual radioactivity levels for unrestricted use of the facility, of financial assurance that funds will be available for performing required decommissioning activities at the end of facility operation (including premature closure) and of the facilitation of decommissioning. Preliminary NRC staff positions on these items have been presented in draft NUREG reports.(13,14,15)

(3) Decommissioning of a nuclear facility generally has a positive environmental impact. At the end of facility life, termination of a nuclear license is a required objective. Such termination requires decontamination of the facility such that the level of any residual radioactivity remaining in the facility or on the site is low enough to allow unrestricted use of the facility and site. Commitment of resources, compared to operational aspects, is generally small.

The major environmental impact of decommissioning is the commitment of small amounts of land for waste burial in exchange for reuse of the facility and site for other nuclear or nonnuclear purposes. Since in many instances, such as at a reactor facility, the land has valuable resource capability, return of this land to the commercial or public sector is highly desirable. In decommissioning of nuclear facilities, the objective of NRC regulatory policy is to ensure that for the commercial sector, proper and explicit procedures are followed in major key areas to mitigate any potential for adverse impact on public health and safety or on the environment.

In the following sections, major recommended regulatory particulars are described with respect to decommissioning alternatives and timing, planning, financial assurance, and residual radioactivity. In the final section, the manner in which such recommendations are to be explicitly incorporated into the regulatory process is discussed.

15.1 MAJOR REGULATORY PARTICULARS

15.1.1 Decommissioning Alternatives and Timing

15.1.1.1 Decommissioning Alternatives

Decommissioning of a nuclear facility should have as its primary objective thorough decontamination of radioactivity resulting in unrestricted use of the facility at the earliest practical time. In certain situations, the potential for occupational exposure reduction, resulting from radioactive decay, would allow for the use of safe storage or entombment. An upper limit for the period of safe storage or entombment is about 100 years, which is consistent with EPA recommended policy on institutional control reliance for radioactivity confinement.

Categorization of decommissioning alternatives is broken into three major classifications which are referred to in this EIS by the pseudoacronyms DECON, SAFSTOR, and ENTOMB. These terms have been used to discuss potential decommissioning alternatives in the nuclear facility studies presented in this report. Briefly, they have the following meanings:

DECON is an alternative where immediately at the end of facility life the equipment, structures and portions of the site containing radioactive contaminants are decontaminated to a level which permits the facility to be released for unrestricted use shortly after cessation of facility operations. For facilities contaminated with long-lived nuclides or which have reasonable decommissioning occupational dose, DECON would be the preferred decommissioning alternative from a health and safety standpoint. This is because it can satisfy the objective of achieving unrestricted use of the facility at the earliest practical time, without adversely affecting the health and safety of the public or workers.

SAFSTOR is an alternative in which the facility is placed (preparation for safe storage) and maintained (safe storage) in such condition that the facility can be safely stored and subsequently decontaminated to levels which permit release of the facility for unrestricted use (deferred decontamination). Depending on the radioactivity level at the end of the safe storage period, decontamination at the final stage may consist of only a radiation survey to verify that the radioactive constituents have decayed to an appropriate unrestricted access level. The primary health and safety advantages of using SAFSTOR are the reduction of occupational exposure and quantities of radioactive waste as a result of radioactive decay. In most situations in decommissioning, the amount of the reduction of occupational exposure compared to DECON is considered to be of marginal significance to health and safety.

ENTOMB is an alternative where at the end of facility life the equipment containing radioactive contaminants is encased in a structurally long-lived material, e.g., concrete. The entombed structure is appropriately maintained and continued surveillance is carried out until the entombed radioactive contamination decays to a level permiting unrestricted use of the facility. This alternative is primarily used for facilities contaminated with short-lived radionuclides. When used appropriately, ENTOMB can reduce occupational exposure as well as the volume of radioactive waste. One of the difficulties with ENTOMB for any complex structure is to appropriately ensure that only short-lived radionuclides remain in the entombed structure. Failure to do this would require a deferred decontamination, which could be more costly than that done for the SAFSTOR alternative.

In summary, from the analysis of the technical data base, as discussed in earlier sections of the EIS, decommissioning can be accomplished safely and at modest cost shortly after cessation of facility operation, and, therefore, DECON would be considered the more preferable alternative in most instances since it would restore the facility and site for unrestricted use in a much shorter time period than SAFSTOR or ENTOMB. Completing decommissioning and releasing the facility for unrestricted use eliminates the potential problems which may result from the increased number of sites used for the confinement of radioactively contaminated material, as well as eliminating potential health, safety, regulatory, and economic problems associated with maintaining the site. Delay in the completion of decommissioning, as in the case of SAFSTOR or ENTOMB, would be primarily for reasons of health and safety considerations, since it is recognized that with delay there may be reduction in occupational dose and radioactive waste volume for some facility types due to radioactive decay. Delay for such reduction would require additional justification since the amount of such reduction is of marginal significance in its effect on health and safety. For example, use of such delay may be justified at a multiple facility site where phased decommissioning may be appropriate. Even for this situation, decommissioning should be accomplished in as short a time as is reasonable. For this example, for a reactor at a multiple facility site where radioactive cobalt is the principle contaminant, there would be little dose reduction due to decay after a delay of 30 years. Therefore, it is recommended that the maximum delay for the reactor in this example be 30 years. For other facilities, the maximum delay considered reasonable will depend on the facility type and the contaminant isotopes involved.

15.1.1.2 Timing

Timing of decommissioning is the length of time after facility shutdown that decommissioning should reasonably last before a license is terminated. As discussed in the various sections on the specific facilities (Sections 4 through 14) in this EIS, a major difference between the facilities is the particular radionuclides most critical to decommissioning for that facility. For example, for PWRs, Co-60, with a half-life of 5.3 years, is the nuclide which must be considered most in decontamination efforts; while for a mixed oxide plant, long lived nuclides, such as Pu-239 with a half-life of 24,390 years, are more important. These nuclides can be referred to as critical/abundant nuclides. Based on the technical studies of the various nuclear facilities discussed in this report, this section categorizes potentially viable decommissioning alternatives for specific critical/abundant facility contaminant radionuclides. This is done by classification of alternatives in terms of three major characteristic critical/abundant radionuclide half-life time limits of 5, 30, and greater than 30 years. These result in the following:

(1) Critical/abundant radionuclide half-life limit of about 5 years -- An example of such a half-life limit would be Co-60 which is the critical/abundant nuclide for nuclear reactors. The following decommissioning alternatives would be permissible:

   (a) DECON, with appropriate occupational exposure management, i.e., the conducting of decommissioning activities in such a manner that doses to workers are kept ALARA.

   (b) SAFSTOR, which includes a safe storage condition for up to 30 years (i.e., an optimum dose reduction time for the limiting case).

   (c) ENTOMB, which includes surveillance for about 100 years provided that during this time the radioactivity will decay to levels permitting release of the facility for unrestricted use. Long-lived activation products, such as Nb-94 and Ni-59, would preclude the use of this alternative for a reactor. Even if an attempt was made to remove reactor internals containing long-lived activation products, it would be difficult to obtain certification that radioactivity had decayed to unrestricted levels because of the uncertainty resulting from the complexity of the contaminated structure.

(2) Critical/abundant radionuclide half-life limit of about 30 years - An example of such half-life limits are Cs-137 and Sr-90, which are the critical/abundant nuclides for a fuel reprocessing plant. ENTOMB would not be permitted because decay to levels permitting unrestricted use of the facility would exceed the recommended 100-year administrative control period. The following decommissioning alternatives would be potentially viable.

   (a) DECON, with appropriate occupational exposure management, i.e., the conducting of decommissioning activities in such a manner that doses to workers are kept ALARA.

   (b) SAFSTOR, which includes a safe storage condition for up to 100 years (i.e., an optimum dose reduction time for the limiting case).

(3) Critical/abundant radionuclide half-life limit greater than 30 years - An example of such a half-life limit is Pu-239, which is a critical/abundant nuclide for a mixed oxide plant. The time for radioactive decay to levels

pemitting unrestricted use of the facility would exceed 100 years and preclude use of the ENTOMB alternative. Moreover, radioactive decay would not reduce occupational dose to any appreciable extent, thus minimizing any advantages which would be gained by SAFSTOR. The following decommssioning alternative would be viable.

(a) DECON.

15.1.2 Planning

15.1.2.1 Initial Plans

Planning for decommissioning is a critical item for ensuring that the decommissioning activity is accomplished in a safe, efficient, and timely manner. For the facilities considered in this report, the majority of the actual decommissioning will occur when facility operation ceases. It is necessary, however, to implement an initial decommissioning plan prior to licensing of a nuclear facility to appropriately facilitate desired decommissioning objectives. In the case of existing licensees such plans would be submitted within a reasonable time period following the implementation of decommissioning regulations. It is recognized that many factors can influence the final decommissioning plan (i.e., technology advances, changing regulatory requirements, economics, political climate). Therefore, initial plans do not require the level of detail required for the final version. They must demonstrate, however, that certain aspects of decommissioning planning required prior to commissioning and during facility operation are adequately addressed. The initial plan should address the following:

(1) Decommissioning alternative - The method for decommissioning to levels permitting unrestricted use of the facility should be tentatively selected and described. The major intent of such characterization is to provide sufficient detail to identify the approximate cost of the decommissioning activity. Such cost estimate is to be used in connection with financial qualification requirements to ensure that adequate funds will be available at the time of decommissioning. The cost estimates and method of assurance of funding for the decommissioning alternative should be described. The cost estimates may be based on acceptable information from the literature such as the Battelle PNL decommissioning studies discussed throughout this report. Periodic review and updating, as required, should be required in this aspect of planning.

(2) Facilitation - There are many aspects of facility design and operational procedures that could greatly affect decommissioning in terms of improved health and safety and reduction of radioactive waste volume. Description should be presented of such design and operational procedures.

Suggestions for facilitation considerations are presented in the Battelle PNL facility decommissioning studies as well as a preliminary special study on facilitation of reactor decommissioning.(10) While there are many situations where decommissioning facilitation will improve operational aspects from an economic point of view (such as periodic decontamination of coolant crud buildup), emphasis should be placed on the primary objective of improved health and safety in effecting the decommissioning operations. For example, for complex structural facilities, emphasis should be placed on radioactive component access and, where appropriate, remote manipulatory machinery requirements, regardless of whether these will be economically advantageous from an operational point of view. While cost is a consideration in implementing facilitation, there are many situations whereby such cost impact is minimzed through early design or operational considerations.

(3) Records - Recordkeeping of relevant information required to support decommissioning is an important aspect of facilitation. A description of plans to collect and safeguard records and archive files should include complete as-built and as-revised drawings and specifications, significant operational occurrences, and site-specific background data.

15.1.2.2 Final Plans

Final decommissioning plans should contain much greater detail than initial plans. Such plans should be submitted in a timely way to the NRC for review and approval prior to the initiation of any decommissioning activity to avoid delay of decommissioning after facility shutdown. For a major power reactor such review and approval could take on the order of a year. Final plans should include the following:

(1) Decommissioning Alternative - A detailed description of the alternative to be used for decommissioning the facility should be presented. Such description should include major procedures and techniques utilized that are related to health and safety during the decommissioning operations (which continue until radioactivity levels permitting unrestricted access are achieved).

Plans for processing and disposing of all radioactive waste should also be included. Such plans should realistically assess the availability of permanent waste burial grounds. If such space is unavailable, then contingency plans should be presented which address use of available temporary above-ground waste storage. Depending on a variety of circumstances, such temporary waste storage may be accomplished offsite or onsite and would require NRC review and approval on an individual case basis.

A detailed certification plan for a final termination survey should also be presented to ensure that remaining residual radioactivity is within NRC-approved levels for releasing the facility for unrestricted use. Although the SAFSTOR or ENTOMB alternatives may have been selected, which would require a complete termination survey at some future time, unrestricted access to portions of a facility/site may be desirable prior to full decommissioning.

A detailed cost estimate should be included based on the alternative selected to ensure that appropriate decommissioning funds will be available prior to active initiation of the decommissioning operations.

(2) Schedule - Detailed schedules for completion of all decommissioning activities (related to work plans) should be submitted.

(3) Administrative Controls - Detailed plans describing the organization and procedures required for accomplishing decommissioning should be submitted. Such plans should include a delineation of responsibilities and requirements for review, audit, and reporting. Details of the quality assurance program to be used should also be submitted.

(4) Specifications - Proposed specifications by the licensee on controls and limits for procedures and equipment to ensure occupational and public safety, to accomplish decommissioning, should be submitted.

(5) Training - Details of a program for training employees and contractor personnel for required decommissioning should be submitted.

15.1.3 Financial Assurance

The primary objective of the NRC with respect to decommissioning is to protect the health and safety of the public. An important aspect of this objective is to assure that, at the time of termination of facility operations (including premature closure of the facility), that adequate funds are available to decommission the facility resulting in its release for unrestricted use. Assurance of this availability of funds ensures that decommissioning can be accomplished in a safe and timely manner and that lack of funds does not result in delays in decommissioning that may cause potential health and safety problems for the public. The need to provide this assurance arises from the fact that there are uncertainties concerning the availability of funds at the time of decommissioning. These uncertainties are of two general types. The first is that the financial solvency of a particular organization is difficult to predict several years into the future when decommissioning of a specific facility is likely to occur. The second type of certainty is that, potentially, a facility could be forced to shut down prematurely.

The nuclear facility licensee has the responsibility for completing decommissioning in a manner which protects public health and safety. Satisfaction of this objective requires that the licensee provide a high degree of assurance that adequate funds for performing decommissioning will be available at the end of facility operation. Because of the possibility of premature closure of the facility, financial assurance provided by the licensee must also contain a mechanism enabling funds for the full cost of decommissioning to be made available at any time during facility operation.

In providing the high degree of assurance necessary that funds are available for decommissioning, there are several possible financing mechanisms which are available to applicants and licensees. The wide diversity in different types of nuclear facilities necessitates that the NRC allow a wide latitude in the implementation of these financing mechanisms. A preliminary NRC staff analysis(14) for providing guidance as to what funding mechanisms provide adequate assurance has led to the following major classification of funding alternatives (used singly or in combination):

(1) Prepayment - Cash or other liquid assets that will retain their value for the projected operating life of the facility are deposited into an account prior to facility startup. This account would be segregated from other company funds.

(2) Decommissioning insurance, surety bonds, letters of credit, and lines of credit - Insurance, most likely for the larger facilities, which could potentially provide for all decommissioning expenses, including potential premature decommissioning, or insurance to cover only costs of premature decommissioning, may be used. The surety bond or credit mechanisms guarantee that the decommissioning costs will be paid should the bond purchaser default. The bond holder still must provide funding for decommissioning through some other method. It appears questionable that bonds of the size necessary and for the time involved with power reactors will be available. However, they appear to be available for facilities that involve smaller costs and time periods. The contractual arrangement guaranteeing the suretys must include a provisions for noncancelability, preferably over the projected operating life of the facility. Sufficient time for NRC notification of surety cancellation must be guaranteed, in any case, to allow for consideration of termination of operating license and required decommissioning. Such forced decommissioning would result if the NRC determined that a loss of surety by the licensee resulted in an unviable financial assurance condition. It should be kept in mind that sureties would be called only if, at the time of cessation of facility operation (or impending loss of surety), licensee decommissioning funds were inadequate or unavailable.

(3) Sinking Funds - The sinking fund or funded reserve approach requires that a prescribed amount of funds, subject to periodic revision, be set aside annually in an account, segregated from other company funds, such that the fund plus accumulated interest would be sufficient to pay for decommissioning costs at the time of termination of facility operation. The fund could be invested in high-grade corporate securities, in State or municipal tax-free securities, in Federal debt obligations or other assets. The disadvantage of the sinking fund approach is that in the event of premature closure of a facility the decommissioning fund would be insufficient. Therefore, the sinking fund would have to be supplemented by decommissioning insurance, or other mechanisms of item (2), which would pay the difference.

Another funding mechanism which has drawn considerable interest and discussion, especially among electric utilities, is that referred to as internal reserve or unsegregated sinking fund. This mechanism usually uses negative net salvage value depreciation which allows estimated decommissioning costs to be accumulated over the life of the facility. In this mechanism, the funds are not segregated from the utility's assets, rather they are invested in utility plant assets and at the end of life bonds are issued against such plant assets and the funds raised are used to pay for decommissioning. Such a mechanism is generally favored by utilities because it is considered to be less expensive in terms of net present value than the options listed above, although, as discussed in Section 2.6, whichever funding mechanism is used should not have a significant impact on the revenue requirements. The problem with the internal or unsegregated funding method is the lack of assurance that funds will be available to pay for decommissioning. Because this method depends on financing internal to the licensee, the unfunded reserve is vulnerable to any event or situation that undermines the financial solvency of a utility. A utility with serious financial troubles would have difficulty raising capital against its decommissioning reserve. In addition, in the event of financial distress of a utility, an internal reserve may not be available to pay for decommissioning costs, but may have to be paid instead to satisfy claims of superior creditors. Under the NRC's responsibility to protect public health and safety by assuring that funds are available for a safe decommissioning, the internal reserve would be considered an adequate funding mechanism only if it were supplemented by substantial additional financing mechanisms (such as insurance or other surety arrangements) that overcome the assurance deficiencies.

A financial assurance plan should be submitted by an applicant prior to licensing the facility. The costs for decommissioning various nuclear facilities is not well established because there has been limited decommissioning experience. Battelle PNL, under contract to NRC, has made detailed cost estimates of most nuclear facilities to provide a data base for licensee cost estimation. The PNL estimates include sensitivity analysis to include licensee situations that may differ from the reference facility cost estimates. The PNL cost estimates, with suitable adjustments to account for licensee facility differences, can be used by an applicant for initial financial assurance plan cost estimates. Information on technology improvements, enhanced decommissioning experience, and inflationary/deflationary cost factors is expected to evolve with time. Consequently, resulting cost estimate improvements of the licensee's financial plan will be periodically required and reviewed. In this way, it is expected that the decommissioning fund available at the time of facility shutdown will not differ significantly from the actual costs of decommissioning.

15.1.4 Residual Radioactivity Levels for Unrestricted Use of a Facility

The objective of selecting residual radioactivity levels for unrestricted use of a facility is to provide a terminal level of radioactivity that will allow unrestricted access to a decommissioned facility and consequent NRC license termination. A selected level at which a facility can be released for unrestricted use, must, of course, be safe and consistent with the ALARA (as low as is reasonably achievable) principle. In addition, selected levels for unrestricted facility use must be verifiable through actual detailed survey measurements of the facility and site, and be within reasonable bounds regarding state-of-the-art survey detection methodology and costs. Risk from radioactivity is measured in terms of potential exposure or related dose to a potentially exposed individual. Therefore, a meaningful representation of a residual radioactivity level can be given in terms of a dose limit (i.e., mrem) or range. Such representation is generic and thus, does not have to specify radionuclide spectra for specific facilities and associated dose receptor pathways. For actual certification survey measurements, the contaminant radioactivity in terms of specific nuclide surface or volumetric concentrations must be specified. Use of appropriate pathway (and receptor usage) analyses provides the method for converting the selected dose value to an equivalent radionuclide specific contaminant concentration (based on existing facility spectra analysis).

In converting selected dose values to specific contaminant concentrations, it is intended to use a dose pathway analysis that provides a realistic assessment of potential dose to an individual. Such assessment takes consideration of population living patterns, as well as constraints on the bioavailability of radioactive materials. Recognition is given to such factors as occupancy being less than 100 percent of the time, sustenance not limited only to the decommissioned site, self-shielding through soil or buildings, and resuspension reduction due to weathering. Thus, use of the realistic analysis methodology attempts to equitably deal with potential risk to an individual taking into account societal considerations of risk and cost.

The EPA has the responsibility for setting decommissioning residual radioactivity levels considered safe for release of a facility for unrestricted access but they have not yet done so. However, there have been discussion with EPA relative to providing preliminary guidance for NRC in establishing these limits, consistent with eventual EPA requirements.

Due to the variety of facility types and radionuclides involved it is not feasible to set a single dose limit that would be valid under all conditions for all facilities. It is necessary to assess the radiological impact in terms of the radionuclides and pathways involved and the costs and benefits which result. Based on these considerations and on consideration of the residual radioactivity limits discussed in this section, the following recommendations are made:

(1) A residual radioactivity level for permitting release of a nuclear facility for unrestricted use should be ALARA. Guidance in establishing such a limiting level is best expressed in terms of a value which bounds the dose for the majority of facilities discussed in this report. This value is determined to be 10 mrem/yr whole-body dose equivalent, (see Section 2.5.3 for a definition), but could be lower for specific facilities. The 10 mrem/yr limit is chosen recognizing that it may be impractical and unnecessary in some cases to meet the 5 mrem/yr limit previously mentioned (in conclusion (2) of Section 2.5.2) because of cost-benefit considerations and problems in detectability, sampling, and/or exposure patterns. Discussion with EPA has indicated that the 10 mrem/yr limiting value would not be considered unreasonable. In all cases, a dose limit above 1 mrem/yr would require justification. For a few situations, it is expected that residual limits will be outside the bounds of the 1 to 10 mrem/yr range. For these special situations, case-by-case analysis in term of cost and benefit effectiveness will be required to establish appropriate limiting levels.

(2) Such dose rates and associated allowable contamination levels should be based on realistic dose assessment methodology.

Consideration of the realistic factors discussed above can be applied in order to convert the radiation levels as measured by the terminal radiation survey to a dose that a member of the public would realistically be expected to be exposed to from the decommissioned nuclear facility. Based on these factors and on a potential unrestricted use of the facility and site considered to be limiting in terms of estimated dose to the public, the realistic assessment of the dose to a member of the population (see Section 2.5.3), exposed to radiation levels corresponding to those of the certification survey, would be within the 1-10 mrem/yr range. Such residual radioactivity levels are consistent with previous NRC regulatory guidance(16) and with the former AEC guidance and implementation of various decommissioned AEC facilities.(17,18)

Oak Ridge National Laboratory, in a preliminary study being done for NRC on nuclear facility terminal certification surveys,(19) has indicated that, for a PWR, certification of such residual levels are well within technology capability and can be done with reasonable cost effectiveness. This preliminary study indicated that certification of a residual radioactivity level of 1 mrem/year was difficult to attain technologically and could lead to excessive costs. Certification of a 5 mrem/year level was well within technological capability and could be done for the order of $250,000 or less (i.e., less than about 0.6% of estimated overall PWR decommissioning costs). Certification of a 25 mrem/year level was estimated to cost not much less than that for 5 mrem/year (about 10% less than the 5 mrem/year cost).

There should be no significant additional decontamination effort required as a result of the termination survey, perhaps only cleanup of a few hot spots indicated by the survey. This is because the extensive efforts required to decontaminate the highly contaminated facility to low radioactivity levels will result in residual radioactivity levels well below the limits which permit release of the facility for unrestricted use. In addition, spot surveys will be carried out periodically during the decommissioning period so that at the time of the termination survey, the licensee is confident that decontamination effects have achieved the acceptable residual radioactivity levels in most instances. Thus, because there should not be significant additional decontamination necessary after completion of the termination survey, the major cost and effort expected for verifying the required residual radioactivity levels for unrestricted facility use should come from the certification survey. As indicated above for the PWR example, these survey costs are expected to be a small fraction of the total decommissioning cost. The benefit of the costs of verification is certainly clear in the assurance provided that the radioactivity levels at a decommissioned facility are below levels acceptable for unrestricted use and will not require additional decontamination at some future time.

In addition, cost-benefit considerations are involved in the evaluation of the extent of facility decontamination necessary to reduce radioactive contamination to levels considered acceptable for releasing the facility for unrestricted use. However, decontamination costs of a facility are essentially independent of the level to which it must be decontaminated as long as that level is in the range of 1 to 25 mrem/yr to an exposed individual.(4),(7) Therefore, cost-benefit considerations are not expected to have a major impact on the GEIS results concerning reactor and most non-reactor decommissionings. Cost-benefit may be a consideration in the removal of ore piles at non-fuel-cycle ore processing facilities where cost of disposal of the ore is very large.

15.2 REGULATIONS

As discussed in Section 15.1, consideration must be given to the decommissioning of a facility during the conception, commissioning, and operating stages of a nuclear facility lifetime. Regulations which have relevance for decommissioning planning and accomplishment are contained in Title 10 of the Code of Federal Regulations (10 CFR), Parts:

Part No.	Title
30	Rules of General Applicability to Domestic Licensing of Byproduct Material
40	Domestic Licensing of Source Material
50	Domestic Licensing of Production and Utilization Facilities
51	Licensing and Regulatory Policy and Procedures for Environmental Protection
70	Domestic Licensing of Special Nuclear Material
72	Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation.

Many of the regulatory requirements contained in the aforementioned regulations do not contain the explicit consideration of necessary decommissioning requirements discussed in this section (although many of the explicit decommissioning requirements have been required as a condition of NRC licensing in case-by-case instances).

Development of a separate regulation which specifically addresses decommissioning was considered. However, such a separate regulation would be cumbersome because it would need to contain many of the requirements already presented in 10 CFR Parts 30, 40, 50, 51, 70, and 72. Since decommissioning requirements are an integral consideration in nuclear facility licensing and operation, it is appropriate in terms of simplicity, efficiency, and reduction of regulatory burden, to amend the pertinent parts of the existing regulations to explicitly include appropriate decommissioning requirements.

To provide a clear presentation of the NRC's overall decommissioning policy objectives and to establish the framework for the rulemaking, it is recommended that an NRC decommissioning policy statement be issued prior to issuance of the proposed regulatory amendments. This will provide the required coherence of presentation required for critical review and commentary by the public, as well as provide guidance in the use of proposed regulatory changes with respect to intent and implementation of these changes.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and the National Technical Information Service, Springfield, VA 22161.

**Available for purchase from the National Technical Information Service.

***Available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

GLOSSARY

Abbreviations, acronyms, terms, and definitions used in this study and directly related to decommissioning work and related technology are defined and explained in this section. The section is divided into two parts, with the first part containing abbreviations and acronyms, and the second part containing terms and definitions (including those used in a special sense for this study). Common terms covered adequately in standard dictionaries are not included.

ABBREVIATIONS AND ACRONYNMS

AEC	Atomic Energy Commission
ALAP	As Low As Practicable
ALARA	As Low As is Reasonably Achievable(a)
BEIR	Biological Effects of Ionizing Radiation
CFR	Code of Federal Regulations(a)
Ci	Curie(a)
DF	Decontamination Factor(a)
DOE	Department of Energy
DOT	Department of Transportation
DPM	Disintegrations per Minute(a)
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air (Filters)(a)
HLW	High Level Waste(a)
HVAC	Heating, Ventilation, and Air Conditioning
ICRP	International Committee on Radiation Protection
LLW	Low Level Waste(a)
m^3	Cubic Meters
mR	Milliroentgen(a)
mrad	Millirad(a)
mrem	Millirem, also see rem
MT	Metric Ton(a)
MTHM	Metric Ton of Heavy Metal
MWd/MTU	Thermal Megawatt-day per Metric Ton of Uranium, the Burnup(a)
MWe	Megawatts electric
MWt	Megawatts thermal
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission

(a) See the following section, Glossary Definitions, for additional information or explanation.

ORNL	Oak Ridge National Laboratory
OSF	Overall Scaling Factor
PNL	Pacific Northwest Laboratory
R	Roentgen(a)
rad	Radiation Absorbed Dose(a)
rem	Roentgen Equivalent Man(a)
SNM	Special Nuclear Material(a)
$T_{1/2}$	Half Life, Radiological(a)
TRU	Transuranic
UF_6	Uranium hexaflouride
UO_2	Uranium dioxide

GLOSSARY DEFINITIONS

Actinides--A series of heavy radioactive metallic elements of increasing atomic number (Z) beginning with antinium (89) or thorium (90) through element hahnium of atomic number 105.

Activation--The process by which a material is made radioactive by its exposure to neutrons or protons. Material in the primary coolant of a reactor may become activated in their passage through the reactor core. Also, the internals of a reactor may become radioactive due to their exposure to neutrons.

Activity--See Radioactivity.

Agreement State--A State with which the NRC has entered into an agreement, under provisions of the Atomic Energy Act of 1954 and its amendments, in which States assume regulatory responsibility over byproduct, source material, and small quantities of special nuclear material.

Airborne Radioactive Material--Radioactive particulates, mists, fumes, and/or gases in air.

ALARA--A regulatory design philosophy to maintain radiation exposure As Low As is Reasonably Achievable.

Atomic Number (Z)--The number of protons in the nucleus of an atom; also its positive charge. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements form a complete series from 1 (hydrogen) through 105 (hahnium).

Background--The level of radioactivity from sources other than the one directly under consideration, in this case those existing without the presence of the nuclear facility.

Beta Decay--Radioactive decay in which a beta particle is emitted or in which an orbital electron capture occurs.

Bio-availability--The degree to which radionuclides are available for transmittal through the food chain to the exposed individual.

Burial Grounds--Areas designated for storage of packaged radioactive wastes in soils below the surface.

Burnup, Specific--The total energy released per unit mass of a nuclear fuel. It is commonly expressed in megawatt-days per metric ton of fuel material.

Byproduct Material--Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.

Cask--A heavily shielded shipping container for radioactive materials. Some casks weigh as much as 100 metric tons.

Certification survey--See terminal radiation survey.

Chemical decontamination--Decontamination accomplished by the use of chemical solutions to remove surface films containing radioactive materials.

(a) See the following section, Glossary Definitions, for additional information or explanation.

Code of Federal Regulations (CFR)--The Code of Federal Regulations is a documentation of the general rules by the Executive departments and agencies of the Federal Government. The Code is divided into 50 titles that represent broad areas subject to Federal regulation. Each title is divided into Chapters that usually bear the name of the issuing agency. Each Chapter is further subdivided into Parts covering specific regulatory areas.

Commissioning--The licensing and startup of a nuclear facility.

Container--See cask.

Contamination--Undesired material that have been deposited on the surfaces, or are internally ingrained into structures or equipment, or that have been mixed with another material.

Continuing care--See safe storage

Curie--A special unit of radioactivity. One curie equals 3.7×10^{10} nuclear transformations per second. (Abbreviated Ci.) Several fractions of the curie are in common usage:

- o Millicurie. One-thousandth of a curie. Abbreviated mCi (3.7×10^7 d/s).
- o Microcurie. One-millionth of a curie. Abbreviated μCi (3.7×10^4 d/s).
- o Nanocurie. One-billionth of a curie. Abbreviated nCi (37 d/s).
- o Picocurie. One-millionth of a microcurie. Abbreviated pCi (0.037 d/s).

Custodial SAFSTOR--A minimum cleanup and decontamination followed by a period of safe storage with active protection systems in service and completed by deferred decontamination. The active protection systems (i.e., principally ventilation) are kept in service, the site is secured against intrusion by physical barriers and by guards, and use of the facility and site is limited to nuclear activities.

Decay, Radioactive--A spontaneous nuclear transformation in which a particle, gamma radiation, or x-ray radiation is emitted.

Decommissioning--To safely remove a nuclear facility, including its site, from radioactive service and to dispose of associated radioactive materials. The level of any residual radioactivity remaining in the facility or on the site after decommissioning must be low enough to allow unrestricted use of the facility and site.

Decommissioning insurance--A mechanism for assuring the funding of decommissioning which could provide funds for all decommissioning expenses, including those for premature closure of the facility, or alternatively, funds to cover only costs of premature decommissioning in the event that other mechanisms provided by the insureds were insufficient.

DECON---To immediately remove all radioactive materials down to levels which are considered acceptable to permit the property to be released for unrestricted use.

Decontamination--Those activities employed to reduce the levels of contamination in or on structures, equipment and materials. Also used to infer decontamination to levels corresponding to release of a facility for unrestricted use.

Decontamination Factor (DF)--The ratio of the initial concentration of an undesired material to the final concentration resulting from a treatment process. The term may also be used as a ratio of quantities.

Deferred Decontamination--Those actions required after the safe storage period of SAFSTOR to disassemble and remove sufficient radioactive or contaminated materials from the facility and site, to permit release of the property for unrestricted use.

Design Basis Accident--A postulated accident believed to have the most severe expected impacts on a facility. It is used as the basis for safety and structural design.

Disintegration, Nuclear--The transformation of the nucleus of an atom from one element to another, characterized by a definite half-life and the emission of particles or electromagnetic radiation.

Disintegration Rate--The rate at which disintegrations occur, characterized in units of inverse time, i.e., disintegrations per minute (dpm), etc.

Dismantlement--Those actions required to disassemble and/or remove radioactive or contaminated materials from the facility and site.

Dispersion--A process of mixing one material within a larger quantity of another. For example, the mixing of material released to the atmosphere with air causes a reduction in concentration with distance from the source.

Disposal--The disposition of materials with the intent that the materials will not enter man's environment in sufficient amounts to cause a health hazard.

Dose, Absorbed--The mean energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 0.01 joules/kilogram in any medium (100 ergs per gram).

Dose commitment--The integrated dose that results unavoidably from an intake of radioactive material starting at the time of intake and continuing to a later time (usually specified to be 50 years from intake).

Dose, Equivalent--Expresses the amount of radiation that is effective in the human body, expressed in rems. Modifying factors associated with human tissue and body are considered. Equivalent dose is the product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. Referred to as Dose in this report.

Dose, Occupational--The exposure of an individual to radiation as a result of his employment, expressed in rems.

Dose Rate--The radiation dose delivered per unit time and measured, for instance, in rem per hour.

Enrichment--The ratio (usually expressed as a percentage) of fissile isotope to the total amount of the element (e.g., the % of ^{235}U in uranium.)

ENTOMB--To encase and maintain property in a strong and structually long-lived material (e.g., concrete) to assure retention until radioactivity decays to a level acceptable for releasing the facility for unrestricted use.

Exposure--The condition of being made subject to the action of radiation; also frequently the quantity of radiation received. The special unit of exposure is the roentgen (see Roentgen).

Exposure Pathway--The mechanisms by which radioactive material passes from the source of the material through the environment to an exposed individual.

External exposure--As used in this EIS, an exposure pathway in which an individual is externally exposed directly to radioactive materials dispersed in the air (immersion) or is exposed directly to surfaces containing radioactive materials.

Facilitation--As used in the context of decommissioning, consideration to be given to facility design and normal operational procedures with the primary purpose of reducing occupational and public radiation dose during the decommissioning process.

Facility--The physical complex of buildings and equipment within a site.

Final Inventory Cleanout--An extensive inventory cleanout and special nuclear material audit conducted upon termination of normal facility operations. Since these cleanout operations are also conducted periodically during normal operation for audit and contamination control purposes, this procedure is not considered part of decommissioning and its cost is not included as a decommissioning cost.

Fission--The splitting of a heavy atomic nucleus into two lighter parts (atomic nuclides of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.

Fission Products--The lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms. It also includes the nuclides formed by the fission fragments' radioactive decay.

Food Chain--The pathways by which any material passes through man's environment through edible plants and/or animals to man.

Fuel Assembly--A grouping of fuel elements (hollow rods filled with nuclear fuel for LWRs) that supply the nuclear heat in a nuclear reactor. A fuel element or rod is the smallest structurally discrete part of a reactor or fuel assembly that has nuclear fuel as its principal constituent.

Fuel Cycle--The series of steps involved in supplying fuel for nuclear power reactors and handling spent fuel and radioactive waste, including transportation. These steps are usually divided up as the head end and back end as follows:

Head end: Mining, milling, conversion, enrichment, and fabrication of fuel.

Back end: Includes reactors, spent fuel storage, spent fuel reprocessing, mixed-oxide fuel fabrication, and waste management.

Fuel Element--A rod, tube, or other form into which nuclear fuel is fabricated to use in a reactor.

Gamma Rays--Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are best stopped or shielded against by dense materials such as lead or uranium. These rays originate from within the nucleus of the atom.

Gaseous--Material in the vapor or gaseous state, but can include entrained liquids and solids. A gas will completely fill its container regardless of container shape or size.

Half-Life, Radioactive--The time in which half the atoms of a particular radioactive substance disintegrates to another nuclear form. Each radionuclide has a unique half-life. Measured half-lives vary from millionths of a second to billions of years.

Heavy Metal--Jargon used in reference to metals with atomic numbers 90 and greater. It usually refers to nuclear fissile or fertile fuels such as thorium, uranium, and plutonium.

HEPA filter--A filter used in facility ventilation systems whose purpose is to remove particulate material from the ventilation air stream.

High-Level Wastes--Intact fuel assemblies that are being discarded after having completed their useful lives in a nuclear reactor (spent fuel) or the portion of the wastes generated in the reprocessing of spent fuel that contain virtually all of the fission products and most of the actinides not separated out during reprocessing.

Hot Spots--Areas of radioactive contamination higher than average.

Ingestion--As used in this EIS, an exposure pathway in which radioactive materials reach the exposed individual through the ingestion of food and water.

Inhalation--As used in the EIS, an exposure pathway in which radioactive materials reach the exposed individual through the breathing process.

Institutional Control Reliance--The degree to which reliance can be placed on the ability of man-made institutions to both safely confine the radioactivity in and prevent the intrustion into a nuclear facility while it is in safe storage or while it is entombed.

Insurance for decommissioning--See decommissioning insurance.

Internal reserve--A mechanism for the funding of decommissioning which generally uses negative net salvage value depreciation, which allows estimated decommissioning costs to be accumulated over the life of the facility. In this mechanism, funds are not segregated from the licensee's assets; rather they are invested in company plant assets and at the end of life bonds are issued against such plant assets and the funds raised used to pay for decommissioning.

Ion Exchange--A chemical process involving the selective absorption or desorption of various chemical ions in a solution onto a solid material, usually a plastic or resin. The process is used to separate and purify chemicals, such as fission products from plutonium or "hardness" from water (i.e., water softening).

Letters of credit--A mechanism for the funding of decommissioning which guarantees that the bank issuing the letter of credit will lend funds to the borrower for payment of decommissioning costs up to the amount specified for the period of and under terms specified for the letter of credit. Similar to lines of credit.

Licensed Material--Nuclear source material, special nuclear material, or nuclear by-product material received, possessed, used, or transferred under a license issued by the Nuclear Regulatory Commission.

Long-Lived Nuclides--For this study, radioactive isotopes with long half-lives typically taken to be greater than about ten years. Most nuclides of interest to waste management have half-lives on the order of one year to millions of years.

Low-Level Wastes--Wastes contaminated with radioactive materials emitting primarily beta or gamma radiation, not high-level waste (see high-level wastes) and which are not transuranic wastes, i.e., they contain less than 10 nanocuries per gram of transuranic elements (see transuranic waste).

Management (Waste)--The planning, execution, and surveillance of essential functions related to radioactive waste, including treatment, solidification, packaging, interim or long-term storage, transportation, and disposal.

Man-rem--A measure of radiation dose distributed to a population. To calculate radiation dose to the population, the dose equivalent in rem received by each person in the population is summed.

Mass Number--The number of nucleons (protons and neutrons) in the nucleus of an atom. (Symbol: A).

Maximum Exposed Individual--The hypothetical member of the public who receives the maximum radiation dose. For the common case where exposures from airborne radionuclides result in the highest radiation exposure, this individual resides at the location of the highest airborne radionuclide concentration and eats food grown at that location.

Megawatt-day--A unit for expressing the energy generated in a reactor; specifically, the number of millions of watt-days of heat output per metric ton of fuel in the reactor. Also, the net electrical output in millions of watts of electrical energy averaged over one day.

Megawatt Days per Metric Ton of Uranium--Amount of thermal megawatt-days produced per metric ton of uranium; also called burnup. (See also specific power.)

Metric Ton--1000 kilograms.

Mixed Oxide--A mixture of uranium dioxide and plutonium dioxide.

Monitoring--Taking measurements or observations for recognizing the status, or significant changes in conditions or performance, of a facility or area.

Negative Net Salvage Value Depreciation--An accounting procedure which allows depreciation to be collected in a manner that considers that the salvage value of a nuclear facility is actually negative, i.e., the price of any salvageable equipment is outweighed by the cost of decommissioning. Thus the net depreciation value of a nuclear facility is its original capital cost plus its decommissioning cost.

Net present worth--As used in this EIS, the cost of decommissioning in terms of 1978 dollars.

Normal Operating Conditions--Operation (including startup, shutdown, and maintenance) of systems within the normal range of applicable parameters of an operating facility.

Nuclear Reaction--A reaction involving a change in an atomic nucleus, such as fission, fusion, particle capture, or radioactive decay.

Offsite--Beyond the boundary line marking the limits of plant property.

Onsite--Within the boundary line marking the limits of plant property.

Operable--Capable of performing the required function.

Package--The packaging plus the contents of radioactive materials.

Packaging--The assembly of radioactive material in one or more containers or other components necessary to assure compliance with prescribed regulations.

Passive SAFSTOR--A partial cleanup and decontamination effort initially, followed by a period of safe storage and completed by deferred decontamination. During the period of safe storage, all systems are deactivated, the structures are secured by strong physical barriers and continuous remote monitoring, and the plant is limited to nuclear use only, while the site may have non-nuclear uses.

Physical decontamination--Decontamination accomplished by the use of mechanical cleaning means or by the removal of the surface itself.

Plant--The physical complex of buildings and equipment, including the site.

Premature closure--The permanent shutdown of a nuclear facility prior to the end of its planned operating lifetime.

Preparation for Safe Storage--Those cleanup and decontamination activities required during the initial stages of SAFSTOR in order to prepare the facility for the safe storage period.

Prepayment--A mechanism for the funding of decommissioning in which cash or other liquid assets that will retain their value for the projected operating life of the facility are deposited into an account prior to facility startup. This account would normally be segregated from other company managed funds.

Protective Clothing--Special clothing worn by a person in a radioactively contaminated area to minimize the potential for contamination of his body or personal clothing and to control the spread of contamination.

Quality Assurance--The systematic actions necessary to provide adequate confidence that a material, component, system, process, or facility performs satisfactorily, or as planned, in service.

Quality Control--The quality assurance actions that control the attributes of the material, process, component, system, or facility in accordance with predetermined quality requirements.

Rad--A unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joule/kilogram of absorbing material.

Radiation--(1) The emission and propagation of radiant energy through space or through a material medium in the form of waves; for instance, that of electromagnetic waves or of sound and elastic waves. (2) The energy of such waves; and (3) corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown types.

Radiation Background--See Background.

Radioactive Material--Any material or combination of materials which spontaneously emit ionizing radiation, generally alpha or beta particles, often accompanied by gamma rays.

Radioactivity--The number of nuclear transformations occurring in a given quantity of material per unit of time with the emission of particles, gamma radiation, or x-ray radiation. Often shortened to "activity."

Radioactivity, Natural--The property of radioactivity exhibited by more than fifty naturally occurring radionuclides.

Radiological Protection--Protection against the effects of internal and external exposure to radiation and to radioactive materials.

Rate of return--As used in this EIS, the rate that investment by decommissioning funding mechanisms will increase in value.

Realistic Pathway Analysis--A methodology for evaluation of doses to the population from a decommissioned facility, that provides a realistic assessment of the potential dose by taking into account actual conditions that may exist such as occupancy, source of sustenance, self-shielding and decreasing resuspension and bioavailability.

Regulatory Guides--Regulatory Guides are issued by the NRC, to describe and make available to the public, methods acceptable to the NRC staff, for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations and compliance with them is not explicity required. Methods and solutions different from those set out in the guides may be acceptable if they provide a basis for the finding requisite to the issuance or continuance of a permit or license by the NRC.

Rem--A unit of radiation dose equivalence. The radiation dose equivalence in rem is numerically equal to the absorbed dose in rad multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

Repository (Federal)--A site owned and operated by the Federal Government for long-term storage or disposal of radioactive materials.

Residual Radioactivity Levels--As used in this EIS, the amount of radioactively contaminated material remaining in a nuclear facility after decommissioning has been completed and the facility license terminated. To be acceptable, this level must be low enough to permit the facility to be released for unrestricted use.

Restricted Area--Any area to which access is controlled for protection of individuals from exposure to radiation and radioactive materials.

Resuspension--The physical process by which radioactive materials deposited on building or equipment surfaces or on soil become airborne either naturally or as the result of some decontamination procedure.

Risk--As used in this EIS, quantative risk estimation of potential health effects.

Roentgen--A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions. One roentgen equals 2.58×10^{-4} coulombs per kilogram of air. (See also Exposure.)

SAFSTOR--Those activities required to place (preparation for safe storage) and maintain (safe storage) a radioactive facility in such condition that the risk to safety is within acceptable bounds and that the facility can be safely stored and subsequently decontamined to levels which permit release of the facility for unrestricted use (deferred decontamination).

Safe Storage--A period of time starting after the initial decommissioning activities of preparation for safe storage cease and in which surveillance and maintenance of the facility takes place. The duration of time can vary from a few years to on the order of 100 years.

Sealed source--Radioactive material that is encased in a capsule designed to prevent leakage or escape of the radioactive material.

Segregated funding mechanism--As used in this EIS, a term to indicate that the funding mechanism being employed deposits funds in accounts separate from company assets and under control of a party other than the licensee.

Shield--A body of material used to reduce the passage of particles or electromagnetic radiation. A shield may be designated according to what it is intended to absorb (as a gamma ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background, or thermal shield). It may be required for the safety of personnel or to reduce radiation enough to allow use of counting instruments for research or for locating contamination or airborne radioactivity.

Short-Lived Radionuclides--For this study, those radioactive isotopes with half-lives less than about 10 years.

Shutdown--The time during which a facility is not in productive operation.

Sinking Fund--A mechanism for the funding of decommissioning in which a prescribed amount of funds, subject to periodic revision, is set aside at regular intervals such that the fund plus accumulated interest would be sufficient to pay for decommissioning costs at the end of facility operation.

Site--The geographic area upon which the facility is located that is subject to controlled public access by the facility licensee (includes the restricted area designated in the NRC license).

Solid Radioactive Waste--Material that is essentially solid and dry but may contained sorbed radioactive fluids in sufficiently small amounts as to be immobile.

Solidification--Conversion of radioactive wastes (gases or liquids) to dry, stable solids.

Special Nuclear Material--Plutonium, uranium enriched in the isotopes 233 or 235, and any other material as defined in 10 CFR 70 by the NRC.

Surety bond--A mechanism for the funding of decommissioning which guarantees that funds equal to the face value set for the bond will be paid in the event that the bond purchaser defaults. These bonds could be bought by the licensees from surety companies.

Surface Contamination--Contamination that is the result of the deposition and attachment of foreign materials to a surface.

Surveillance--Those activities necessary to assure that the site remains in a safe condition (including inspection and monitoring of the site, maintenance of barriers to access to radioactive materials left on the site, and prevention of activities on the site that might impair these barriers).

Survey--An evaluation of the radiation hazards incident to the production, use, release, disposal or presence of radioactive materials or other sources of radiation under a specific set of conditions.

Technical Specifications--Requirements and limits that encompass nuclear safety but are simplified to facilitate use by plant operation and maintenance personnel. They are prepared in accordance with the requirement of 10 CFR 50.36, and are incorporated by reference into the amended license issued by the NRC.

Terminal Radiation Survey--The radiation survey conducted near the end of the decommissioning period the purpose of which is to certify that decommissioning of the facility has resulted in residual radioactivity levels acceptable for releasing the facility for unrestricted use.

Transuranic Elements--Elements with atomic number (Z number) greater than 92. Includes plutonium and uranium isotopes.

Transuranic Waste--Any waste material measured or assumed to contain more than a specified concentration (i.e., proposed as 10 nanocuries of alpha emitters per gram of waste, or more presently proposed as 100 nanocuries/ cm^3 of waste ^{239}U) of transuranic elements.

Unfunded reserve--See internal reserve.

Unrestricted access--The condition of a nuclear facility after decommissioning is complete and the facility license is terminated. At this time the general public would be allowed use of the facility without radiation protection controls.

Unsegregated sinking funds--See internal reserve

Volumetric contamination--Contamination that is contained within the volume of the contaminated material, such as activation products.

Wastes, Radioactive--Equipment and materials (from nuclear operations) that are radioactive and for which there is no further known use.

Whole Body Dose Equivalent--As used in this report for the discussion of residual radioactivity levels, a single dose equivalent number that is a summation of dose equivalent from major organs multiplied by respective weighting factors related to cancer producing risk.

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16. ABSTRACT *(200 words or less)* This draft generic environmental impact statement was prepared as part of the requirement for considering changes in regulations on decommissioning of commercial nuclear facilities (including that occurring following premature closure). Consideration is given to the decommissioning of pressurized water reactors, boiling water reactors, fuel reprocessing plants, mixed oxide fuel fabrication plants, uranium hexafluoride conversion plants, uranium fuel fabrication plants, independent spent fuel storage installations, nuclear energy centers, and facilities for handling non-fuel-cycle byproduct, source and special nuclear materials. Decommissioning has many positive environmental impacts such as the return of possibly valuable land to the public domain and the elimination of the proliferation of radioactively contaminated facilities with a minimal use of resources. Major adverse impacts are shown to be routine occupational radiation doses and the commitment of nominally small amounts of land to radioactive waste disposal. Other impacts, including radiation doses, are minor. Mitigation of potential health, safety, and environmental impacts requires more specific and detailed regulatory guidance than is currently available. Recommendations are made as to regulatory decommissioning particulars including such aspects as appropriate initial planning requirements prior to commissioning, final planning requirements prior to termination of facility operations, residual radioactivity level for unrestricted access, and assurance of funding for decommissioning.

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