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B. Snyder

Ms. Jacquelyn G. Tarrer
The Kegler's Loft
9942 Chireno
Dallas, Texas 75220

JUL 16 1981

Dear Ms. Tarrer:

This is in reply to your recent letter about disposal sites and deactivation methods for nuclear power plants.

Enclosed for your information is Chapter 8 on "Waste Management" from the Annual Report of the Nuclear Regulatory Commission. This discusses sites for disposal of low-level and high-level radioactive wastes.

Also enclosed are the Foreword, Introduction, and Summary of Report NUREG/CR-0672 published in June 1980 on "Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station." The Foreword lists a number of other reports on decommissioning nuclear facilities, including one on pressurized water reactors.

These documents indicate that substantial progress is being made on methods for disposal of radioactive wastes and decommissioning of nuclear power plants. As to the economics of nuclear power, electric utilities currently operating nuclear plants are finding that their total costs of generating electricity are less than for plants burning coal or oil. The higher construction costs for nuclear plants are outweighed by their lower fuel costs. Of the alternative sources of energy you mention, wind, solar, and geothermal will not be available or feasible in sufficient quantity to replace nuclear power, which is currently providing 11 to 12 percent of the total electrical energy in the United States.

Sincerely,

Original Signed by
Gary G. Zech

Gary G. Zech, Chief
Technical Support Branch
Office of Nuclear Reactor Regulation

M-12
Waste

Enclosures:
1. Chapter 8 of NRC Annual Report for 1980.
2. Excerpts from NUREG/CR-0672.

*SEE PREVIOUS SHEET FOR CONCURRENCE

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SURNAME	*PFine/LLM	GGZech					
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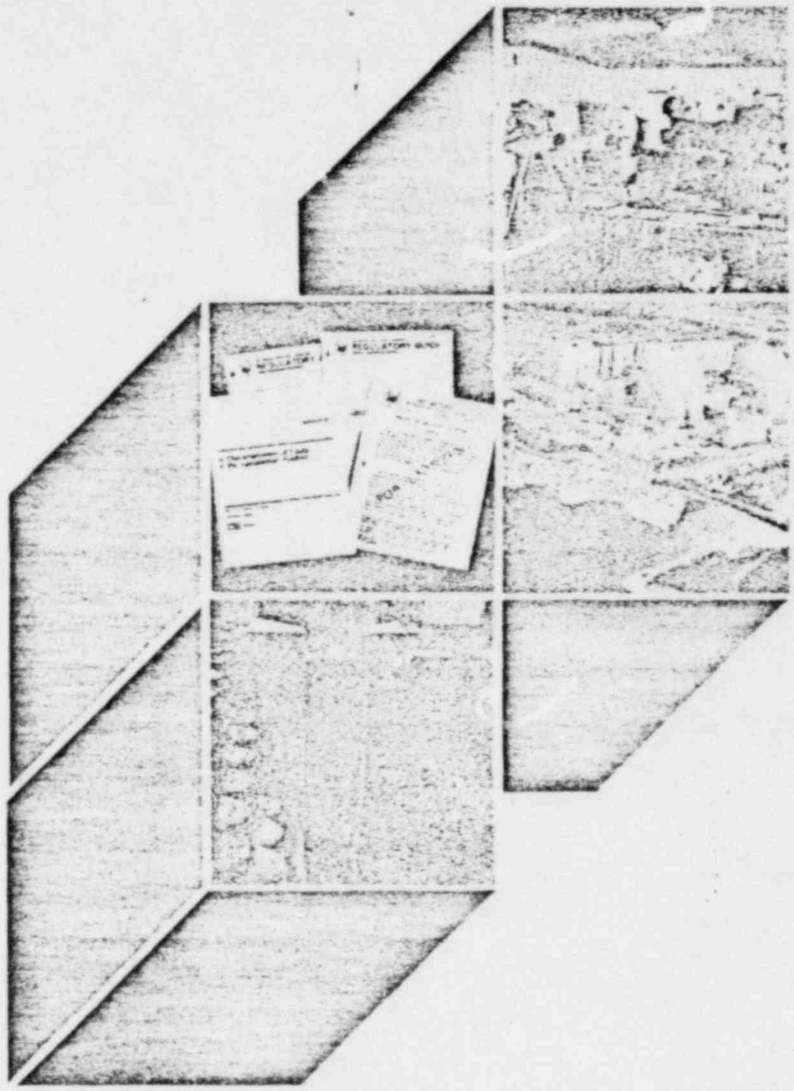
1980 Annual Report

CHAPTER 8



U.S. NUCLEAR
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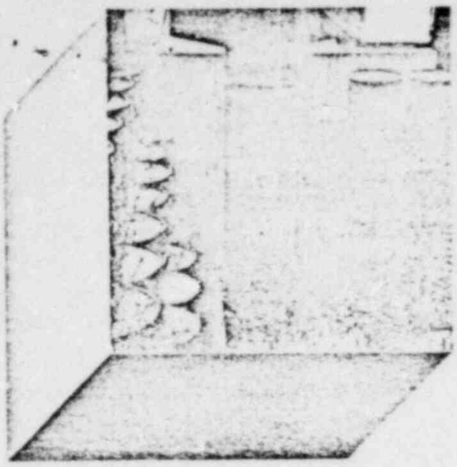


8 Waste Management

The NRC's nuclear waste management activities are directed by the Office of Nuclear Material Safety and Safeguards (NMSS). These functions, which cover the regulation of all NRC licensed source, byproduct and special nuclear material waste and uranium mill tailings, include the following:

- Developing the criteria and framework for regulating high-level waste management, including the technical bases for licensing, and licensing actions on proposals for high-level waste commercial repositories.
- Licensing and regulating low-level waste disposal facilities and providing the technical support for such regulation.
- Licensing and regulating uranium recovery facilities and associated mill tailings. These operations include uranium mills, heap-leaching facilities, ore-buying stations, solution mining (insitu), and byproduct uranium recovery.

The interim storage of spent nuclear reactor fuel and transportation of all forms of radioactive waste are discussed in Chapter 6.

Overview of 1980 Activity

In 1980, the NRC staff worked on regulations to ensure that methods for disposing of radioactive waste meet the Commission's goal for safe disposal. To accomplish this goal, each of the three waste management program areas focused on licensing and regulatory improvements.

During the year, the NRC released, in two parts, a regulation for high- level waste repositories (10 CFR Part 60). The proposed procedural portion was published in the Federal Register as a proposed rule (44 FR 7048). In May 1980, the technical criteria for regulating geologic disposal was published as an advance notice of proposed rulemaking (45 FR 31393). The staff also prepared a draft of the regulatory guide on format and content of site characterization reports.

In addition, the NRC completed models for assessing radionuclide transport in bedded salt, continued preparing a draft Site Characterization Report Review Plan for DOE site characterization reports, and worked on an assessment of the extent to which the Department of Energy's programs were directed at developing the information required to comply with NRC's proposed high-level waste regulations.

In the low-level waste disposal area, the NRC concentrated on developing comprehensive licensing criteria. In 1981, the staff expects to issue drafts of the low-level waste regulation (10 CFR Part 61) and its environmental impact statement. Supporting regulatory guides are also being drafted.

In the uranium recovery program, the NRC continued to improve the regulatory basis for licensing decisions, and to take actions to ensure that uranium recovery operations are properly conducted to protect the public and the environment A total of 52 licenses were issued, renewed, or amended, and 21 project reviews were conducted to assist Agreement States. In addition, regulations related to uranium mill tailings (amendment to 10 CFR Part 40) were issued in final form (45 FR 65521), and the supporting final Generic Environmental Impact Statement on Uranium Milling was issued in October 1980 (45 FR 67177). Supporting regulatory guides for the uranium milling industry are also being developed.

Internal Coordination

The Waste Management Review Group, (formed in May 1979) consists of representatives of the major

> **NATIONAL WASTE MANAGEMENT PLAN**
>
> On February 12, 1980, President Carter announced a comprehensive radioactive waste management program based on recommmendations issuing from the Interagency Review Group on Radioactive Waste Management (IRG) which made its final report in March 1979. (The NRC, as an independent regulatory agency, participated as a non-voting member of the IRG. See 1978 Annual Report, pp. 93-94 and 1979 Annual Report, pp. 146-147.) The President's program includes the following elements:
>
> - The Department of Energy (DOE), as lead agency in the Executive Branch for management and disposal of radioactive wastes, will prepare a National Plan for Nuclear Waste Management with the cooperation of other relevant Federal agencies. It is anticipated that a draft will be issued in 1980 for public and Congressional review.
> - Creation of a 19-member State Planning Council consisting of 15 governors and other elected officials, and four members of executive departments and agencies, to work with the Executive Branch and Congress on waste management decisions and actions.
> - Adoption of an interim planning strategy for high-level wastes which relies on mined geologic repositories capable of accepting both waste from reprocessing and unreprocessed commercial spent fuel. The program focuses on locating and characterizing four to five potentially suitable sites and selection of one or more by 1985 for licensing and operation by the mid-1990's.
> - Legislation will be sought to extend NRC licensing authority over all DOE transuranic waste disposal facilities and any new DOE sites for commercial low-level waste disposal.
> - DOE will assist States in efforts to establish a reliable commercial low-level radioactive waste disposal system.
> - EPA will consult with the NRC to resolve issues of overlapping jurisdiction and the two agencies should seek to improve and expedite regulatory actions.
> - The President urged the Nuclear Regulatory Commission to conduct in a timely and thorough manner its proceeding to determine whether or not it has confidence that wastes produced by nuclear power reactors can and will be disposed of safely.
>
> Proposed legislation dealing with a number of elements in the President's program was before the Congress as fiscal year 1980 ended.

NRC program offices. The group is responsible for coordinating all NRC waste management technical assistance and research projects. The group assists the Director of NMSS in making in-depth technical evaluations, eliminating duplication or overlap, and reviewing documentation for procurement methods. In 1980, the group reviewed 75 technical assistance projects, and also examined approximately 100 descriptive summaries for fiscal year 1981 technical assistance projects. In 1980, the group also initiated the development of procedures to achieve consistency and integration of total NRC waste management efforts.

Another coordinating activity of the NRC waste management program in 1980 was the presentation of the waste management program and budget to the advisory Committee on Reactor Safeguards (ACRS). In February 1980, the ACRS reported favorably to Congress on the research aspects of the program (NUREG-0657).

HIGH-LEVEL WASTE PROGRAM

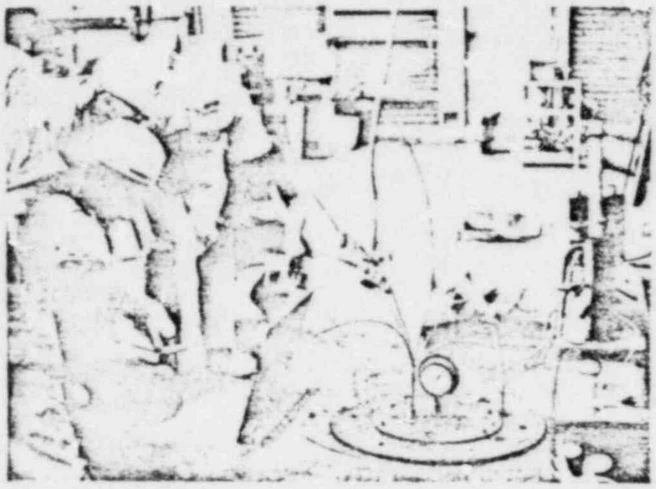
Regulatory Development

In 1980 the NRC made significant progress in developing regulations for the management of high-level radioactive waste and supporting guidance in the form of staff technical directives and regulatory guides.

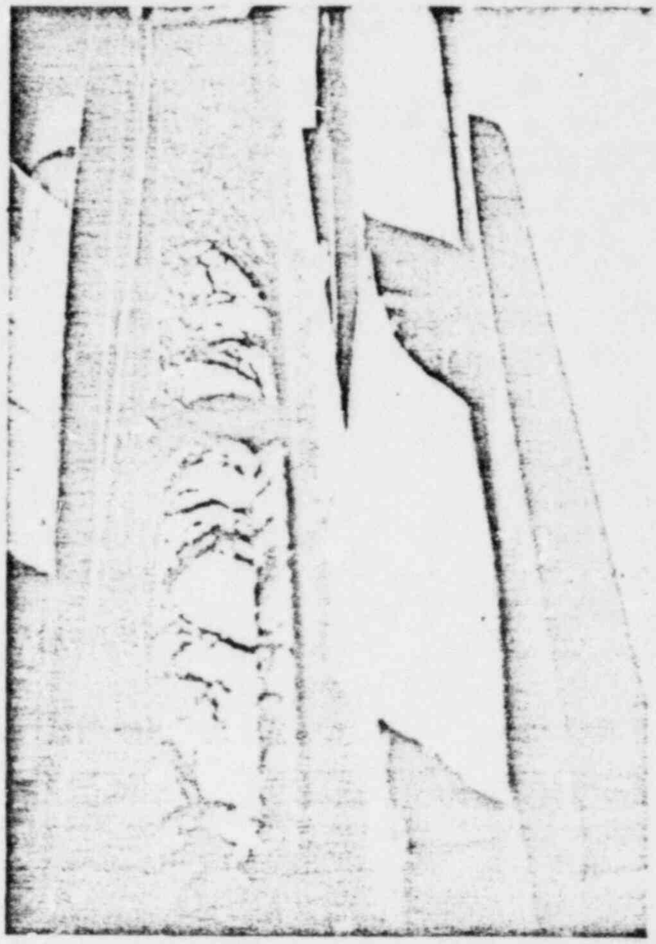
The proposed regulation (10 CFR Part 60) for licensing the disposal by DOE of high-level wastes in geological repositories has been developed in two parts. The first section, setting forth proposed procedures, was published for public comment in December 1979 (44 FR 7048). It contains general provisions, license information, State participation procedures and specifications for reports, tests, and inspections and enforcement. These procedures call for a four-stage review process with opportunity for public participation at each stage.

In May 1980, the technical portion of 10 CFR Part 60 was published as an advance notice of proposed rulemaking (45 FR 31393). It contains requirements for ownership, siting design, waste packaging, retrieval of waste, and monitoring. The advance notice informs the public of the technical criteria being considered and allows the opportunity for reply. In 1981, the procedural portion of the regulation will be published as a final rule, and the technical sections will also be published for public comment as a proposed rule. An environmental impact appraisal for the technical criteria is being prepared.

As a part of the rulemaking process, the NRC has obtained peer reviews of the technic' rule by



High level waste specialists from the NRC staff traveled to numerous locations where the Department of Energy is studying geologic settings which may be suitable for waste-repository sites. The photo above shows NRC and DOE staffers 500 feet below ground in a salt dome as they examine instrumentation to measure brine migration. This visit, to the Avery Island Salt Mine in Louisiana, was one of several stops made by the NRC team during an extended tour of the Mississippi-Louisiana-Texas Gulf Interior Salt Dome region in September 1980. A similar visit had been made earlier, in July, to the Hanford, Washington area. At right is a section of caprock core taken from a salt dome for use in studying the porosity and permeability of this unit, the dissolution history of the dome, and other characteristics important in considerations of waste-repository suitability. Samples such as this were taken from several salt domes examined as part of the DOE program.



environmental, industrial, academic, and public interest representatives. These peer reviews were conducted by the University of Arizona; the Keystone Institute of Keystone, Colo.; and the Resolve Institute of Palo Alto, Calif.

Regulatory Guides

Also under development are regulatory guides specifying the information needed to support an application for a high-level repository, including Site Characterization Reports, Environmental Reports, and Safety Analysis Reports. During the year, NRC worked on a draft of the Standard Format and Content Guide for the Site Characterization Report. This guide, scheduled for completion in 1981, describes the information needed to identify siting issues, determine the status of each issue, and present plans for resolution of issues, if necessary. It also specifies information required on how areas were selected for characterization, on alternative sites that are being considered, the technical data necessary to describe the site, conceptual design of the underground facility, waste form and emplacement environment, and performance analysis. The NRC will provide additional guidance to DOE in regulatory guides being developed for the Environmental Report and Safety Analysis Report.

Technical Directives. Another form of regulatory guidance regarding a high-level waste repository application is provided by technical directives which represent a staff position on a major issue. These staff recommendations may subsequently be incorporated into a regulatory guide. In 1980, the Waste Management staff issued technical directives to DOE on the resolution of issues related to site characterization and geochemical research. Additional directives are planned on waste form and packaging, performance assessment, siting, and repository design.

Reviewing DOE Site Investigations

In 1980, the NRC performed several reviews of DOE's site screening activities. The NRC is continuing to review and comment on the site screening geological investigations at Hanford, Wash., and at the Gulf Interior Salt Domes. In 1981, reviews will be extended to other sites in various geological media.

In its program of upgrading site characterization review capability, the NRC is continuing to develop radionuclide transport models for domed salt, bedded salt, basalt, welded tuff, and granite. During the year, Sandia Laboratories transferred to the NRC staff a porous flow model, called the Sandia Waste Isolation Flow and Transport Model (SWIFT). This model will be used to evaluate radionuclide transport in bedded salt and possibly in domed salt. The NRC is also fashioning a fracture flow model, which will be used to evaluate radionuclide transport in basalt, granite, and other fractured media. The NRC also is developing, under contract, modeling capability for both the repository environment and biosphere transport of radionuclides. In 1981, these models will be transferred to the NRC staff for evaluation.

In a continuing assessment of the national high-level waste program, the NRC will advise DOE on its development of a generic environmental impact statement on commercially generated radioactive waste as well as an environmental impact statement concerning defense high-level waste. (See 1979 Annual Report, pp. 148-149.)

Other Interagency Efforts

During 1980, the NRC was associated with a variety of interagency programs dealing with high-level waste management.

One such effort is the Earth Science Technical Plan, on which the NRC provided comments. The plan was developed by DOE and the U.S. Geological Survey to formally organize the individual earth-science research tasks directed toward a geologic repository for radioactive waste. As a commenting agency, the NRC will give technical assistance and review the plan.

Review is continuing of the standard for disposal of high-level radioactive waste being developed by the Environmental Protection Agency (EPA), which is responsible for standards to protect against radiation in the general environment. The NRC will implement the final standard for repositories of high-level waste. During 1980, the staffs of the NRC and EPA conferred frequently on regulatory development, and consultation will continue on the evolving standards affecting NRC programs.

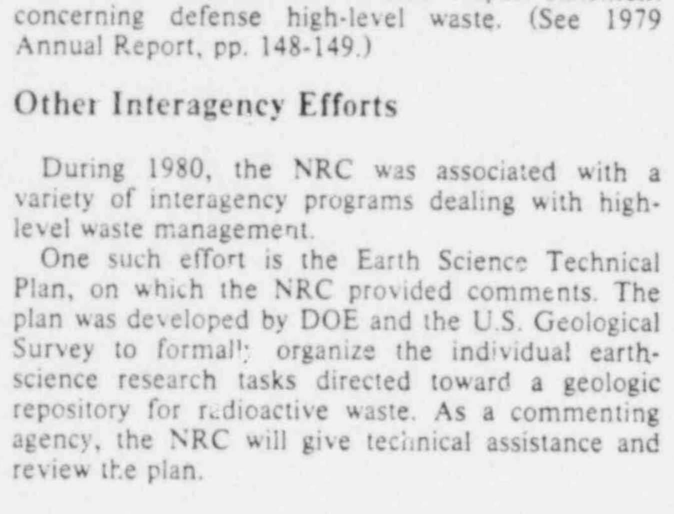
During the report period, the NRC reviewed the efforts of the Materials Characterization Board, a DOE-funded organization which is developing leaching tests. The NRC will continue to comment on the technical activities of the Board.

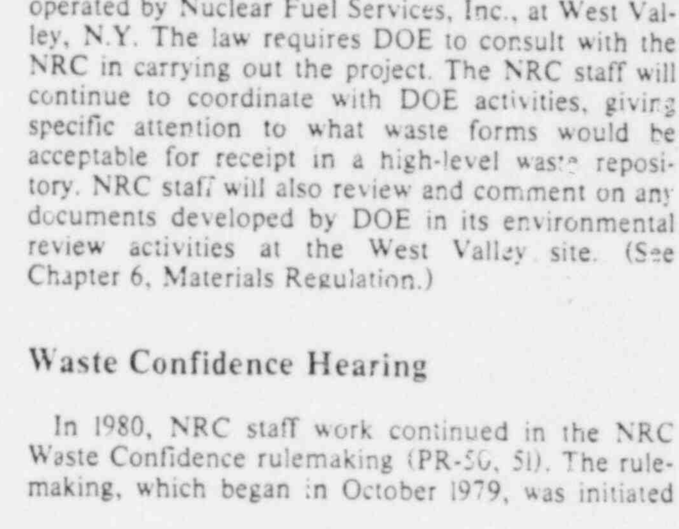
Another major activity in NRC's interagency high-level waste management program is its review of DOE's activities in the West Valley project in New York.

The West Valley Demonstration Project Act (P.L. 96-368, signed by the President, October 1. 1980) authorizes DOE to undertake the solidification and disposal of the liquid high-level waste stored at the site of the spent fuel reprocessing plant formerly operated by Nuclear Fuel Services, Inc., at West Valley, N.Y. The law requires DOE to consult with the NRC in carrying out the project. The NRC staff will continue to coordinate with DOE activities, giving specific attention to what waste forms would be acceptable for receipt in a high-level waste repository. NRC staff will also review and comment on any documents developed by DOE in its environmental review activities at the West Valley site. (See Chapter 6, Materials Regulation.)

Waste Confidence Hearing

In 1980, NRC staff work continued in the NRC Waste Confidence rulemaking (PR-50, 51). The rulemaking, which began in October 1979, was initiated





by the Commission in order to generically assess the current degree of assurance that radioactive wastes can be safely disposed of, to determine when such disposal or off-site storage will be available, and to determine whether radioactive wastes can be safely stored on-site past the expiration of existing facility licenses until off-site disposal or storage is available.

After the first prehearing conference in January 1980, the presiding officer determined that the proceeding would deal only with disposal of spent fuel and not with high-level reprocessing waste, and that issues concerning transportation are beyond the scope of the hearing. The NRC staff has provided a large number of documents for participants' use to assure that the record is complete and all technical issues are explored in the proceeding. (See "Commission Decisions" in Chapter 15 for further discussion.)

The storage and transportation of spent nuclear fuel are discussed in Chapter 6.

REGULATING LOW-LEVEL WASTE

Regulatory Development

In 1980, the NRC continued to develop regulatory tools to provide comprehensive standards for low-level wastes. Because present Commission regulations are not specifically tailored for regulation of disposal sites for low-level waste, the staff concentrated on three major projects: a regulation for a low-level waste disposal site (10 CFR Part 61), a supporting environmental impact statement, and amplifying regulatory guides.

In February 1980, the NRC notified the public of the availability of a preliminary draft of 10 CFR Part 61 which outlines licensing procedures, performance objectives, and technical criteria for disposal of low-level waste into a land facility (45 FR 13104).

The first part of the draft regulation deals with administrative and procedural requirements, such as definitions, general application requirements, and financial qualifications of an applicant. The second part of the regulation deals with technical aspects and sets out overall performance objectives and requirements for waste form and content, site characteristics, design and operations, monitoring, closure, and post-operational surveillance.

The final section would outline specific limitations applying to individual disposal methods.

The NRC plans to formally issue the draft regulation and draft environmental impact statement in 1981. Amendments and supplements to the environmental impact statement addressing low specific activity/high volume waste and high specific activity/low volume waste for disposal in other than shallow land burial and intermediate land burial will also be published at a later date.

The draft of the regulation (10 CFR 61) has been circulated for informal public comments, and the Commission has received a variety of written responses. To provide a broad base of early input from State, industry, and public groups, four regional workshops on the draft regulation were held in Atlanta (April 21-22), Denver (July 14-15), Chicago (July 17-18), and Boston (November 6-7). Workshop recommendations have been submitted to NRC and these, as well as other comments will be considered by the NRC staff in the development of the Proposed Part 61 regulation and of the environmental impact statement.

The NRC is continuing research and other work to develop regulatory guides for the low-level waste regulation. The staff is currently drafting guides for the low-level waste application contents, waste classification, site selection, and site closure and funding. To improve the basis of regulatory development, the NRC is funding research efforts in the areas of modeling, waste classification, volume reduction, and treatment of liquid low-level wastes.

Bulldozers work to cover a portion of a containment trench into which low level waste containers have been dumped. When the entire trench has been filled in this manner, a temporary marker indicating the dimensions and content of the trench will be erected. This marker will be replaced by a permanent one as soon as the cover earth has settled and the area has been grassed over. (The four photos present one continuous vista.)

Licensing Activities

In 1980, the staff continued to assess health, safety, and environmental aspects of NRC-licensed low-level waste disposal facilities. The NRC completed its safety review for renewal of a license for disposal of special nuclear materials at Richland, Wash., in November 1979, and continued safety reviews for renewal of a similar license at Barnwell, S.C.

At the Sheffield, Ill. low-level waste burial site the NRC continued to analyze the health, safety, and environmental aspects of the decommissioning of the Nuclear Engineering Co.'s (NECO) facility which has been operating under NRC license. (See *1979 NRC Annual Report,* pp. 149-150.) In the proceeding before an Atomic Safety and Licensing Board, the NRC staff filed suggested conditions for site closure and stabilization with the board after a prehearing conference in June 1980. NECO is monitoring and maintaining the site while the legal proceedings are being resolved.

The NRC is continuing research in support of low-level waste disposal licensing activities, including environmental assessments of sites, long-term erosion, hydrology, and trench cap studies. New research and technical assistance projects are underway to address new and unique problems in waste disposal posed by the Three Mile Island (TMI) accident.

Regional imbalance for low-level waste sites continued in 1980 because only one applicant in Kansas, an Agreement State, sought a license. At one time, six sites were licensed to operate in Illinois, Kentucky, New York, Nevada, South Carolina, and Washington, but only three are now operating. Of these, the Beatty, Nev., and Hanford, Wash., sites were both closed on occasion by the States during the past year. Furthermore, the third operating facility at Barnwell, S.C., is reducing by 50 percent the amount of waste it will receive during 1980-81. The governors of Washington, Nevada, and South Carolina have stressed the need for new sites to handle regional disposal needs and expressed the hope that other states will join in addressing the problem.

Assistance to Agreement States

The NRC continues to furnish technical advice to Agreement States regarding low-level waste licensing activities. In May 1980, the NRC staff assisted Kansas in review of the Southwest Nuclear Co.'s application for the use of a salt mine at Lyons, Kansas for the retrievable storage of low-level radioactive material. If requested, the NRC will also provide Kansas with an environmental assessment of the site.

In July 1980, the NRC advised Nevada regarding the application of the Nuclear Engineering Co. for renewal of its license for the low-level waste burial site at Beatty, Nev. South Carolina received NRC technical assistance in 1980 to develop the scope and nature of assistance for a formal agreement. The State of Washington was assisted in its review of a license renewal application for the Richland low-level waste disposal site.

The NRC will continue to work with the States to upgrade requirements at existing disposal sites, and is conducting research to give Agreement States a better technical basis for making regulatory decisions.

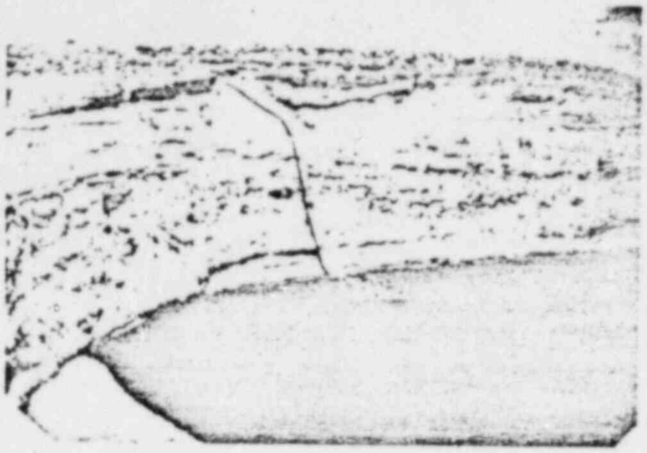
REGULATING URANIUM RECOVERY AND MILL TAILINGS

Licensing Activities

The NRC is responsible for assuring that uranium recovery facilities are constructed, operated, and decommissioned in a manner that will protect the public health and safety and the environment. The NRC places a high priority on assuring that operating mills are brought into compliance with the EPA's new radiation standards (40 CFR 190) and with NRC regulations developed as a result of the Uranium Mill Tailings Radiation Control Act of 1978, as amended (UMTRCA).

During 1980, the NRC staff completed work on 2 new uranium recovery licenses, 4 license renewals, 12 major amendments for facility modifications, 2 amendments to licenses required by EPA standards, 9 license amendments caused by inspection and enforcement activities, and 23 minor and administrative amendments. In addition, 21 technical assistance projects were provided to Agreement State programs. At year-end, there were 15 uranium mills, 9 heap leach/ore-buying stations/byproduct recovery facilities, 13 research and development solution mining operations, and 2 commercial solution mining activities authorized under NRC license.

During the year, the NRC worked with State and industry officials on a problem at the Irigaray Uranium Solution Mining Project in Wyoming, which is an NRC licensee. In April 1980, an NRC order was issued to the licensee to suspend production because of evidence of uncontrolled vertical excursions of leaching solutions. The licensee was required to provide geologic and hydrologic data demonstrating that control of the mining process and restoration of the groundwater are achievable in the proposed mine field areas. The NRC is still studying the advisability of continued operations and what additional license conditions may be warranted.



A mined-out pit is used as a mill tailings pond at the Union Carbide uranium mill in Gas Hills, Wyo. At left, the tailings are sent directly from the mill to the clay-lined pond by means of a slurry. At right, the water from the pond is pumped back up to the mill for use in the milling operation to convert raw uranium ore to "yellowcake" (U_3O_8), a uranium concentrate used as feed material for further conversion to uranium hexafluoride and ultimate refinement for reactor fuel or other uses.

Regulatory Development

In 1980, the NRC continued efforts to upgrade regulations for uranium recovery operations and associated tailings. In October, the NRC released the final Generic Environmental Impact Statement (GEIS) on Uranium Milling (NUREG-0706) along with regulations on mill tailings, which constitute minimum national standards. The regulations, which focus primarily on tailings disposal as mandated by UMTRCA, also specify broad criteria for mill operations and decommissioning. Development of the final GEIS included a benefit-cost analysis of a wide range of alternatives for controlling emissions from uranium mills and for uranium mill tailings disposal impacts to populations nearby and far from mills, where the short- and long-term consequences were considered. Public comments on the final GEIS and on the associated regulations were received in written form, and at public meetings in Denver, Colo., and Albuquerque, N.M. These public comments were addressed in the final GEIS.

The regulations on uranium milling are cast primarily in the form of broad performance objectives. The NRC is developing regulatory guides to provide more specific information on how to meet these performance objectives. Some 20 additional guides will be needed to more fully implement controls dealing with uranium recovery and mill tailings management. Work on these guides was initiated in 1980, and will continue for several years.

A draft guide on standard format and content of license applications (including environmental reports) for in situ uranium extraction was issued in July 1980.

Technical Assistance to Agreement States

The UMTRCA established a number of new requirements affecting the NRC Agreement States program. In its technical assistance program, the NRC assures that Agreement State criteria used to license and regulate uranium recovery operations are compatible with criteria for similar operations under NRC jurisdiction. Under UMTRCA and implementing regulations, the Agreement State role remains a substantial one. (See also Chapter 10.)

The NRC provided technical assistance in 1980 to California, Colorado, Arizona, New Mexico, Oregon, Texas, and Washington in the licensing and regulation of uranium recovery operations. This included 21 project reviews, covering uranium mills, heap-leach operations, solution-mining operations, and research and development activities.

The NRC also continued to provide assistance to New Mexico in its assessment of the Church Rock tailings impoundment area where a dam failure released large quantities of radioactively contaminated water and sediment in July 1979. (See 1979 Annual Report pp. 146-152.) NRC staff worked with State officials to analyze the effects on contaminated areas downstream from the Church Rock area and to verify cleanup. The NRC also helped prepare a draft report on the incident (Survey of Radionuclide Distributions Resulting from the Church Rock, New Mexico Uranium Mill Tailings Pond Dam Failure).

Remedial Action at Inactive Sites

The NRC continued to carry out the mandate of Title I of the UMTRCA which requires review of

DOE's remedial action program at inactive tailing sites and other former ore processing areas. The Commission provides reviews, concurrences, and licensing actions during the remedial process. The NRC reviewed the initial phases of several DOE actions in 1980, and worked out with DOE a detailed plan for subsequent interaction between the agencies.

In conformance with a provision in the fiscal year 1980 Supplemental Appropriations and Recission Bill Report (No. 96-829), the NRC staff has developed, in consultation with the State of South Dakota, EPA, the Department of Housing and Urban Development, and the Tennessee Valley Authority (TVA) an Edgemont Cleanup Action Program. The project involves cleanup of tailings located off-site from a defunct uranium mill formerly operated at Edgemont, S.D., and now owned by TVA. During 1980, NRC initiated preliminary work necessary for off-site tailings cleanup, which is scheduled to begin in 1981.

NUREG/CR-0672
Vol. 1

Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station

Main Report

Manuscript Completed: October 1979
Date Published: June 1980

Prepared by
H. D. Oak, G. M. Holter, W. E. Kennedy, Jr., G. J. Konzek

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering Standards
Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. B2117

EXCERPTS

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) As a part of this activity NRC has initiated two series of studies through technical assistance contracts. These contracts are being undertaken to develop information to support the preparation of new standards covering decommissioning.

The basic series of studies will cover the technology, safety and costs of decommissioning reference nuclear facilities. Light water reactors, fuel cycle facilities and byproduct utilization facilities are included. Facilities of current design on typical sites are selected for the studies. Separate reports will be prepared as the studies of the various facilities are completed.

The first report in this series was published in FY 1977 and covered a fuel reprocessing plant;(2) the second was published in FY 1978 and covered a pressurized water reactor;(3) the third of the series was published in FY 1979 and dealt with a small mixed oxide fuel fabrication plant.(4) An addendum to the pressurized water reactor report(5) was issued during FY 1979 which examined the relationship between reactor size and decommissioning cost, the cost of entombment, and the sensitivity of cost to radiation levels, contractual arrangements, and disposal site

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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.

(2) Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant. NUREG-0278, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.

(3) Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1978.

(4) Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant. NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

(5) Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130 Addendum, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

charges. The most recent report in this series dealt with a low-level waste burial ground.[6] The following report, sixth of the series, provides information on the technology, safety and costs of decommissioning a large boiling water reactor power station. Additional topics will be reported on the tentative schedule as follows:

FY 1980 • Uranium Fabrication Plant

FY 1981 • Non-Fuel Cycle Nuclear Facilities

FY 1981 • Multiple Reactor Facilities

The second series of studies covers supporting information on the decommissioning of nuclear facilities. Three reports have been issued in the second series. The first consists of an annotated bibliography on the decommissioning of nuclear facilities.[7] The second is a review and analysis of current decommissioning regulations.[8] The third of this series covers the facilitation of the decommissioning of light water reactors.[9] The major purpose is to identify modifications or design changes to facilities, equipment and procedures which will improve safety and/or reduce costs.

The information provided in this report on the boiling water reactor, 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 report should mail their comments to:

Chief
Fuel Process Systems Standards Branch
Division of Engineering Standards
Office of Standards Development
U.S. Nuclear Regulatory Commission
Washington, DC 20555

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(6) Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground. NUREG/CR-0570, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, May 1980.

(7) Decommissioning of Nuclear Facilities - An Annotated Bibliography. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, September 1978.

(8) Decommissioning of Nuclear Facilities - A Review and Analysis of Current Regulations. NUREG/CR-0671, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

(9) Facilitation of Decommissioning of Light Water Reactors. NUREG/CR-0569, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, December 1979.

The safety impacts of the decommissioning operations on the public are found to be small, with the principal impact on the public being the radiation dose resulting from the transport of radioactive materials to a disposal site.

CHAPTER 1

INTRODUCTION

This report contains the results of a study sponsored by the Nuclear Regulatory Commission (NRC) to conceptually decommission a present-generation boiling water reactor (BWR) power station. The primary purpose of the study is to provide information on the available technology, the safety considerations, and the probable costs for the decommissioning of a large BWR power station at the end of its operating life. This information is intended for use as background data and bases in the modification of existing regulations and in the development of new regulations pertaining to decommissioning activities. It is also intended for use by utilities in planning for the decommissioning of their nuclear power stations.

Decommissioning of a nuclear facility is defined as the measures taken following the facility's operating life to ensure the protection of the public from any residual radioactivity or other hazards present in the facility. Three approaches to decommissioning are considered in this study:

- Dismantlement - The station is decontaminated, the radioactive materials are removed, and the nuclear license is terminated.
- Safe Storage - The radioactive materials and contaminated areas are decontaminated or secured inside the facility, and surveillance and maintenance continue under the conditions of the nuclear license. Eventual dismantlement is necessary if unrestricted release and license termination is desired.
- Entombment - The radioactive materials and contaminated areas are decontaminated, the nonreleasable materials are confined within a monolithic structure, and surveillance and maintenance continue under the conditions of the nuclear

license until either the confined radioactivity has decayed to unrestricted release levels or the entombment structure is dismantled.

The NRC's desire to minimize the number of sites permanently committed to the containment of radioactive material is satisfied by immediate dismantlement or safe storage plus deferred dismantlement. Entombment after removal of the long-lived radionuclides for relatively long but not unreasonable periods will result in decay of the entombed radioactive material to levels low enough for unrestricted use; however, certification that release limits for unrestricted use have been met is very difficult short of dismantlement of the entombed facility.

A broad span of safe storage methods is possible. These methods range from a minimal removal and fixation of residual radioactivity and continual onsite maintenance and surveillance, to an extensive cleanup and decontamination with hardened passive protection of highly radioactive materials and periodic surveillance and maintenance. Each method of safe storage requires some level of continuing care during the holding period.

The Washington Public Power Supply System's Nuclear Project Number 2 (WNP-2), at Hanford, Washington, is used as the reference BWR power station for this study. WNP-2 is a 1155-MWe station that utilizes a nuclear steam supply system with a direct-cycle boiling water reactor manufactured by the General Electric Company. The single-reactor station is assumed to be on a generic site that is typical of reactor locations in the midwestern or middle southeastern United States. The structures, systems, and components are basically typical of the current generation of large BWR power stations.

Sets of work plans are developed for the conceptual decommissioning of the reference BWR power station via dismantlement, one method of safe storage, and entombment. From these work plans estimates are developed for the manpower requirements, the major resource and equipment needs, the volumes of contaminated material packaged for disposal, the costs of accomplishing the work, and the exposure of the decommissioning workers and the public to radiation as a result of the decommissioning efforts. Because widely different work plans and decommissioning techniques can be utilized to achieve the desired decommissioned condition, the results of the study are dependent upon the detailed choices made. The choices of plans and techniques in this study are believed to be realistic and representative of the operations that would be required to safely decommission the reference BWR power station at a reasonable cost.

A suggested dose-based methodology for determining the level of radioactive contamination that could remain on a site or in a facility and still allow unrestricted use of the property is demonstrated. This methodology utilizes the calculated maximum annual dose to the maximum-exposed individual as the basis for determining these levels. The relationship between dose and contamination level is complex, involving the spectrum of residual radionuclides and their exposure pathways to the maximum-exposed individual.

The work plans and the scenarios for airborne release of radioactive materials are used to evaluate the impacts of decommissioning operations on the workers and the public. Estimates are made of radiation exposure, lost-time injuries, and fatalities for each decommissioning approach studied.

The operating techniques, safety impacts, and estimated costs developed in this study are sensitive to specifics of the reference BWR power station. Such specifics include the mixtures and the levels of residual radioactive contamination at final plant shutdown, and the plant size, design, location, and operating history. These specifics must be examined carefully before attempting to apply the results of this study to a different nuclear power station. Some efforts to examine the sensitivity of the study results to plant specifics such as size, radiation dose rates, etc., are presented in this report.

The study results are presented in two volumes. Volume 1 (Main Report) contains the results in summary form. Volume 2 (Appendices) contains the detailed data that support the results given in Volume 1. The supporting data are presented in a manner that facilitates their use for examining decommissioning actions other than those included in this study.

CHAPTER 2

SUMMARY

The results of this study sponsored by the U.S. Nuclear Regulatory Commission (NRC) to conceptually decommission a large boiling water reactor (BWR) power station are summarized in this chapter. The purpose of the study is to provide information on the available technology, the safety considerations, and the probable costs for decommissioning a large BWR power station after 30 full-power years of operation. The principal results are given, in brief, in the following paragraphs, with more-complete summaries presented in subsequent sections.

Immediate dismantlement of the reference BWR is estimated to cost $43.6 million (in 1978 dollars), to require about 2 years for planning and preparation prior to final reactor shutdown, to require about 3-1/2 years of active decommissioning following reactor shutdown, and to result in radiation doses to decommissioning workers of about 1845 man-rem.

Preparing the reference BWR for passive safe storage, safe storage for 30 years, and dismantlement after 30 years is estimated to cost a total of $58.8 million (in 1978 dollars), to require about 1-1/2 years for planning and preparation prior to final reactor shutdown, to require about 3 years to place the facility in passive safe storage, and to result in accummulated radiation doses to decommissioning workers of about 418 man-rem. Continuing care during safe storage is estimated to cost $75,000 per year and would continue until the facility is dismantled. The cost of dismantling the reference BWR after passive safe storage is estimated to be somewhere between $36 million and $26 million, depending on the duration of the safe storage period, to require a time span equivalent to immediate dismantlement, and to result in radiation doses to decommissioning workers that range from 495 man-rem for dismantlement after 10 years of storage to a few man-rem after 50 years of storage.

Entombing the reference BWR after removing the highly activated reactor vessel internals (scenario 1) is estimated to cost $40.6 million (in 1978 dollars), to require about 2 years for planning and preparation prior to final reactor shutdown, to require about 4 years of active decommissioning following reactor shutdown, and to result in radiation doses to decommissioning workers of about 1684 man-rem. Entombing the reference BWR with the highly activated reactor vessel internals left in place (scenario 2) is estimated to cost $35 million and to result in radiation doses to decommissioning workers of about 1573 man-rem. Scenario 2 is really a form of hardened safe storage, and dismantlement will be necessary to obtain unrestricted release of the property.

Costs of continuing care during entombment are estimated to be $40,000 per year. These costs would continue until either the radioactivity can be shown to have decayed to unrestricted release levels, or until the facility is dismantled should an earlier release of the property become necessary.

No detailed estimates of cost and radiation dose are made for dismantlement of an entombed facility. However, it is anticipated that these parameters will have values similar to those for dismantlement following passive safe storage.

2.1 STUDY BASES

The major study bases are:

- The study must yield realistic and up-to-date results.
- The study is conducted within the framework of the existing regulations and regulatory guidance.
- The study is to evaluate decommissioning of an existing single-reactor facility.
- The study is based on 30 full-power years of plant operation.
- The estimated radiation dose rates throughout the plant are based on measured data from operating plants.
- Current and proven decommissioning technology and techniques are used.

- The funding for decommissioning activities is available as necessary to complete the planned activities without fiscal constraint.
- A nuclear waste disposal facility is in operation.
- For decommissioning activities that immediately follow plant shutdown, the staff is composed of the former operations and maintenance personnel.
- All materials whose radioactivity exceed unrestricted release levels are removed from the site before the site is released for unrestricted use.
- The performance of decommissioning activities is relatively trouble-free.
- The study conforms to ALARA occupational exposure philosophies.
- The costs are in 1978 dollars.

The results obtained in this study are specific to these major bases and to the specific assumptions that are derived from them and stated in the appropriate place in the study. Applying these results to situations where the conditions are different from those in this study could produce erroneous conclusions. The sensitivity of the study results to plant-specifics such as size, radiation dose rate, etc., is examined to provide guidance in the application of these results to other plants.

2.2 DECOMMISSIONING ALTERNATIVES

Decommissioning of a nuclear facility is defined as the measures taken following the end of the facility's operating life to ensure the protection of the public from any residual radioactivity or other hazards present in the facility. Three approaches to decommissioning are considered in this study:

- Dismantlement - The station is decontaminated and the radioactive materials are removed. Upon completion, the nuclear license is terminated and the property is released for unrestricted use.
- Safe Storage - with Deferred Dismantlement - The radioactive materials and contaminated areas are decontaminated or secured and the structures and equipment are maintained as necessary to ensure the protection of the public from the residual radioactivity. During

the period of safe storage, use of the property remains limited by the nuclear license. Eventual dismantlement is necessary if unrestricted release and license termination is desired.

- Entombment - The radioactive materials and contaminated areas are decontaminated and the nonreleasable materials are confined within a monolithic structure that provides integrity to ensure the protection of the public from the entombed radioactivity for a time period of sufficient length to permit the decay of the radioactivity to unrestricted release levels. During the period of entombment, the property is maintained as necessary and remains restricted in use by the nuclear license.

2.3 DECOMMISSIONING EXPERIENCE

A review of the documented cases of nuclear reactor decommissioning shows that while the decommissioned facilities were generally small and had operated for relatively short periods of time, the problems encountered tended to be common to all decommissioning undertakings. The review also shows that a wealth of experience exists within the nuclear industry regarding methods and equipment for accomplishing decommissioning, and that there are no major technical impediments to the successful decommissioning of a large BWR power station.

2.4 REGULATORY GUIDANCE FOR DECOMMISSIONING

In general, regulations are in place to cover decommissioning of the reference BWR. In some cases (i.e., security, safeguards, quality assurance), the existing regulations do not speak specifically to decommissioning, but they can readily be interpreted as being applicable.

The following suggestions are made for improving present regulations:

- Centralize or provide an index for all regulations that pertain to decommissioning.

- Modify the existing regulations that apply to decommissioning to include reference to such centralized or indexed application.
- Clearly define the financial qualifications and responsibilities of the licensee for decommissioning.
- Specify which of the existing regulations governing allowable public radiation dose take precedence during the decommissioning of a light-water reactor.
- More clearly define "high-level waste" (with respect to the highly radioactive reactor vessel components) and the associated disposal requirements.
- Provide a common, identifiable reference for acceptable residual radioactive contamination levels for unrestricted release of materials, structures, and sites.
- Specify the requirements for license renewal or extension, should such be necessary at the time of decommissioning.

2.5 FINANCING DECOMMISSIONING

The federal government currently has very little direct involvement in decommissioning financing considerations. NRC regulations simply require the applicant for an operating license to demonstrate the financial resources to cover the estimated costs of both operating and permanently shutting down the facility. However, the importance of financial assurance for decommissioning was recently recognized by the Congress of the United States in the Uranium Mill Tailings Control Act of 1978, which amends the Atomic Energy Act of 1954, providing explicit authority for the NRC to require an adequate bond, surety, or other financial arrangement by uranium mill licensees to ensure site cleanup and reclamation prior to license termination. Furthermore, the NRC is considering financial requirements within the broader context of an overall reevaluation of its policies on decommissioning nuclear facilities.

Three principal financing alternatives for decommissioning a nuclear power station are considered in this study:

- a prepaid decommissioning reserve controlled by an outside entity
- an internal unfunded decommissioning reserve
- a funded reserve or sinking fund controlled by an outside entity.

A fourth alternative, payment of decommissioning costs from other revenues when the funds are required, is considered in less detail because it provides less assurance that funds will be available.

The revenue requirement for each of the financing alternatives is shown in Table 2.5-1, together with assumptions about tax treatment of the revenues. The results show that the revenue requirements are very sensitive to the tax treatment of those revenues.

TABLE 2.5-1. Revenue Requirements for the Financing Alternatives[(a)]

Financing Alternative	Tax Treatment	Annual Payments ($ millions)	Total Payments ($ millions)
Prepayment	Untaxed	2.35	70.4
Internal Unfunded Reserve	Untaxed	1.47	44.0
	Taxed[(b)]	2.72	81.5
Sinking Fund	Untaxed	1.09	32.5
	Taxed[(b)]	2.01	60.2
Paid When Required	Untaxed	--	44.0

(a) Estimated decommissioning cost = $44 million, depreciation lifetime = 30 years, effective interest rate on fund = 2%/yr, effective interest rate on borrowed capital = 4%/yr.
(b) Most likely situation regarding taxes.

2.6 FACILITY AND SITE

The reactor used as the reference facility in this study is the Washington Public Power Supply System's Nuclear Project Number 2, an 1155-MWe station with a Mark II containment system. The nuclear steam supply system is a direct-cycle boiling water reactor manufactured by the General Electric Company, and is generally representative of the current generation of large BWRs. The reference site used in these analyses is typical of a midwestern or middle southeastern river site. This site has been developed for use in a series of studies devoted to the decommissioning of nuclear fuel cycle facilities that is being performed for the NRC by Pacific Northwest Laboratory. Sufficient descriptive information is presented for both the facility and the site to permit the development of the detailed work plans, the costs estimates, and the safety assessments that are the results of this study.

2.7 RADIONUCLIDE INVENTORY

Levels of radioactivity in and radiation dose rates from activated reactor components, from contamination deposited throughout the plant, and from the site soil are calculated and/or derived from existing data. The radionuclides that are the principal contributors to occupational radiation exposure are: immediately after reactor shutdown and during the next 100 years, ^{60}Co; and after 100 years, ^{94}Nb. The amount of radioactivity present in the activated reactor vessel components at the time of reactor shutdown is calculated to be about 6.6 million curies. The calculated radiation dose rates of ^{60}Co from the activated reactor components at reactor shutdown range from a maximum of 120,000 R/hr at the inner surface of the core shroud to 140 mR/hr at the reactor vessel outer surface. The calculated radiation dose rates from ^{59}Ni and ^{94}Nb have maximum values in the core shroud of about 70 mR/hr and 700 mR/hr, respectively. Dose rates at locations throughout the facility range from several hundred R/hr to a few mR/hr, based on a composite of data from operating plants.

Annual atmospheric releases from operating BWRs vary widely, depending on such specific plant factors as size, operating history, and gaseous effluent system design. For this study, the soil contamination levels and the mixtures of radionuclides on the site resulting from deposition of atmospheric releases from the plant during 40 years of normal operation are calculated from measured annual release information.

2.8 EXAMPLE ACCEPTABLE CONTAMINATION LEVELS FOR UNRESTRICTED USE OF THE BWR PROPERTY

A suggested methodology for determining acceptable residual radioactive contamination levels for unrestricted use of the decommissioned reference BWR facility and/or site is presented in this study, and example acceptable contamination levels are calculated. The methodology is based on the concept that no member of the public will be allowed to receive an annual dose in excess of a limit yet to be established by U.S. regulatory agencies. These example acceptable contamination levels are based on an assumed 50-mrem/yr limit. The effect of radioactive decay on these acceptable levels of residual radionuclides both in the facility and on the site is demonstrated by calculating these levels for the radionuclide mixture present at reactor shutdown and for the mixture present 10, 30, 50, and 100 years after shutdown.

For the facility, the acceptable levels of radioactivity are presented in units of surface activity ($\mu Ci/m^2$). Soil contamination values are presented in units of radioactivity per gram of soil sample by assuming mixing of the radiation source with dry soil to depths of 10 mm and 150 mm. After 40 years of normal BWR operation, the residual radioactive contamination is assumed to be mixed to a depth of 10 mm by natural processes. When the site is released, the residual radioactive contamination is assumed to be mixed to a depth of 150 mm as unrestricted activities begin.

A summary of the calculated example radioactive contamination levels that result in an annual dose of 50 mrem to any organ of any individual is given in Table 2.8-1.

TABLE 2.8-1. Summary of the Calculated Example Acceptable Residual Radioactive Contamination Levels for the Reference BWR Facility and Site

	Time Exposure Begins (Years after Shutdown)[a]	Limiting Organ	Acceptable Residual Contamination Levels Corresponding to an Annual Dose of 50 mrem — Surface Contamination (μCi/m²)	Soil Contamination — Mixed to 10 mm (pCi/g)	Soil Contamination — Mixed to 0.15 m (pCi/g)
BWR Facility[b]	0	Lungs	0.55	--	--
	100	Bone	0.82	--	--
BWR Site	0	Bone	0.17	11	0.73
	100	Bone	0.12	8.0	0.53

(a) The time that continuous exposure begins.
(b) In the facility, a determination of acceptable surface radioactive contamination levels, based on the mixture of the radionuclides, is assumed to be used to help determine the necessary decommissioning procedures.

2.9 RADIATION EXPOSURE ESTIMATES

Estimates of accumulated occupational radiation dose are 1845 man-rem for immediate dismantlement, 1684 man-rem for entombment scenario 1 (removal of reactor vessel internals), 1573 man-rem for entombment scenario 2 (reactor vessel internals entombed), and 375 man-rem for placing the facility in passive safe storage, with an additional 7 to 10 man-rem for surveillance and maintenance during periods of continuing care of from 10 to 100 years. Radiation dose associated with deferred dismantlement depends on when the dismantlement takes place. Relatively little additional reduction in accumulated occupational radiation dose is estimated to result from deferring the dismantlement sequence beyond 30 years, and virtually no additional reduction results from deferment beyond 50 years.

The individual estimates of occupational radiation dose for the various decommissioning alternatives are summarized in Table 2.9-1.

Additional radiation dose is received by the transportation workers and by the general public as a result of transporting the spent fuel and the radioactive materials to disposal sites. These radiation doses are summarized in Table 2.9-2.

Table 2.9-1. Summary of Estimated External Occupational Radiation Doses for Decommissioning the Reference BWR

Start of Decommissioning (years after shutdown)	Estimated Radiation Dose to Decommissioning Personnel (man-rem)[a]					
	Immediate Dismantlement	Preparations for Passive Safe Storage	Continuing Care	Entombment		Deferred Dismantlement
				Scenario 1	Scenario 2	
0	1 845	375	--	1 684	1 573	
10	--	--	1.3	--	--	495
30	--	--	6.5	--	--	36
50	--	--	10.0	--	--	3
100	--	--	10.0	--	--	<1

(a)Total dose for passive safe storage with dismantlement deferred for 30 years is the sum of (375 + 6.5 + 36) man-rem.

TABLE 2.9-2. Radiation Dose from Transport of Radioactive Materials from Decommissioning

	Radiation Doses from Transport (man-rem)[a]			
	Immediate Dismantlement[b]	Preparations Passive Safe Storage	Entombment	
			(Scenario 1)	(Scenario 2)
Occupational:				
Truck Transport	110	22	69	51
Rail Transport	5.4	5.4	5.4	5.4
Totals	120	28	75	56
Public:				
Truck Transport	10	2.2	6.7	4.9
Rail Transport	0.5	0.5	0.5	0.5
Totals	11	2.7	7.2	5.4

(a)All values are rounded to two significant figures.
(b)For deferred dismantlement, these values are reduced in proportion to the decay of ^{60}Co activity during the safe storage period.

2.10 DECOMMISSIONING COSTS

All costs are given in terms of 1978 dollars, with 25% contingencies included.

Immediate dismantlement is estimated to cost $43.6 million. The major contributors to the total cost of immediate dismantlement are summarized in Table 2.10-1. The cost for shipment and disposal of radioactive materials is about 25% of the total decommissioning cost. About 50% of the total decommissioning cost is due to staff labor. Energy, equipment, and supply costs constitute about 10, 6, and 5%, respectively, of the total dismantlement cost.

TABLE 2.10-1. Summary of Estimated Costs for Immediate Dismantlement

Cost Category		Estimated Costs ($ millions)[a,b]	Percent of Total
Disposal of Radioactive Materials			
Neutron-Activated Materials	300		
Contaminated Materials	4.909		
Radioactive Wastes	1.469		
Total Disposal Costs		8.678	24.9
Staff Labor		17.561	50.4
Energy		3.519	10.1
Special Tools and Equipment		2.016	5.8
Miscellaneous Supplies		1.859	5.3
Specialty Contractors		0.356	1.0
Nuclear Insurance		0.800	2.3
License Fees		0.051	0.1
Subtotal		34.840	100.0
Contingency (25%)		8.710	
Total, Immediate Dismantlement Costs		43.550	
Other Possible Costs			
Spent Fuel Shipment		3.788	
Facility Demolition and Site Restoration		13.244	
Deep Geologic Disposal of Highly Activated Materials		0.848	
Fuel Channel Disposal		0.617	
Subtotal		18.497	
Contingency (25%)		4.624	
Total, Other Possible Costs		23.121	

(a) Costs adjusted to early 1978.
(b) The number of significant figures shown is for computational completeness and does not imply accuracy to the nearest $1000.

Other possible costs, which include shipment of spent fuel, disposal of fuel channels, disposal of highly activated materials in deep geologic disposal, and demolition of the decontaminated facility, total an additional 23.1 million.

Preparing the reference BWR for passive safe storage is estimated to cost $21.3 million. The major contributors to the total cost of preparations for passive safe storage are summarized in Table 2.10-2. The principal cost item is staff labor, contributing about 66% of the total. Energy, supplies, and disposal of radioactive wastes contribute about 13, 8, and 7%, respectively, to the total cost.

TABLE 2.10-2. Summary of Estimated Costs for Preparations for Passive Safe Storage

Cost Category	Estimated Costs ($ millions)(a,b)	Percent of Total
Disposal of Radioactive Materials (Radioactive Wastes)	1.216	7.1
Staff Labor	11.254	66.1
Energy	2.122	12.5
Special Tools and Equipment	0.351	2.1
Miscellaneous Supplies	1.361	8.0
Specialty Contractors	0.196	1.2
Nuclear Insurance	0.500	2.9
License Fees	0.038	0.2
Subtotal	17.038	100.0
Contingency (25%)	4.260	
Total, Preparations for Passive Safe Storage Costs	21.298	
Other Possible Costs		
Spent Fuel Shipment	3.788	
Fuel Channel Disposal	0.617	
Subtotal	4.405	
Contingency (25%)	1.101	
Total, Other Possible Costs	5.506	

(a) Costs adjusted to early 1978.
(b) The number of significant figures shown is for computational completeness and does not imply accuracy to the nearest $1000.

The cost of continuing care during passive safe storage is estimated to be $75,000 per year.

The cost of deferred dismantlement following passive safe storage for intervals of 10, 30, 50, and 100 years after final reactor shutdown is estimated in constant 1978 dollars to be $36 million, $36 million, $26 million and $26 million, respectively. The lesser costs after the longer intervals are the result of having less contaminated material for packaging, shipment, and burial due to decay of the radionuclides.

Entombing the reference PWR via scenario 1 (removal and disposal of reactor vessel internals) is estimated to cost $40.6 million. The major contributors to the total cost of entombment are summarized in Table 2.10-3. The principal cost item is staff labor, contributing almost 56% of the total for scenario 1. Disposal of radioactive materials, energy, equipment, and supplies contribute about 18, 12, 6, and 6%, respectively, to the total cost.

TABLE 2.10-3. Summary of Estimated Costs Entombment

Cost Category	Entombment Scenario 1			Entombment Scenario 2[c]		
	Estimated Costs ($ millions)[a,b]		Percent of Total	Estimated Costs ($ millions)[a,b]		Percent of Tota
Disposal of Radioactive Materials						
Neutron-Activated Materials	2.394			0		
Contaminated Materials	1.846			1.992		
Radioactive wastes	1.469			1.469		
Total Disposal Costs		5.709	17.6		3.461	12.4
Staff Labor		18.095	55.7		16.999	60.8
Energy		3.775	11.6		3.775	13.5
Special Tools and Equipment		2.016	6.2		0.866	3.1
Miscellaneous Supplies		1.859	5.7		1.859	6.6
Specialty Contractors		0.172	0.5		0.172	0.6
Nuclear Insurance		0.800	2.5		0.800	2.9
License Fees		0.039	0.1		0.039	0.1
Subtotals		32.465	100.0		27.971	100.0
Contingencies (25%)		8.116			6.993	
Totals, Entombment Costs		40.581			34.964	
Annual Continuing Care Costs		0.040			0.040	
Other Possible Costs						
Spent Fuel Shipment		3.788			3.788	
Facility Demolition and Site Restoration		8.059			8.059	
Deep Geological Disposal of Highly Activated Materials		0.495			0	
Fuel Channel Disposal		0.617			0.617	
Subtotals		12.959			12.464	
Contingencies (25%)		3.240			3.116	
Totals, Other Possible Costs		16.199			15.580	

(a) Costs adjusted to early 1978.
(b) The number of significant figures shown is for computational completeness and does not imply accuracy to the nearest $1000.
(c) Scenario 2 will require eventual dismantlement.

Entombment scenario 2 (reactor vessel internals retained within the entombment structure), which is really a form of hardened safe storage, is estimated to cost $35 million.

The cost of continuing care during entombment is estimated to be $40,000 per year for either scenario 1 or scenario 2.

No detailed cost estimates are developed for dismantlement of an entombed reactor since under scenario 1 the intent is to leave the structure intact until the radioactivity has decayed to release levels. Dismantlement is required under scenario 2, and it is anticipated that the costs would be similar to the costs of dismantlement following passive safe storage.

The total cost in constant 1978 dollars for each of the decommissioning alternatives is summarized in Table 2.10-4.

TABLE 2.10-4. Total Estimated Costs for Possible Decommissioning Alternatives

Decommissioning Alternative	Decommissioning Costs ($ millions)[a,b] Number of Years After Reactor Shutdown Dismantlement is Deferred				
	0	10	30	50	100
Immediate Dismantlement	43.6	--	--	--	--
Preparations for Passive Safe Storage	21.3	21.3	21.3	21.3	21.3
Continuing Care	--	0.6	2.1	3.6	7.4
Deferred Dismantlement	--	35.5	35.5	26.4[c]	26.4[c]
Total Cost	--	57.4	58.9	51.3	55.0
Entombment					
(Scenario 1)	40.6	40.6	40.6	40.6	40.6
(Scenario 2)	35.0	35.0	35.0	35.0	35.0
Continuing Care	--	0.3	1.1	1.9	3.9
Deferred Dismantlement[d]	--	~30	~30	~20	~20
Total Cost					
(Scenario 1)	--	--	--	--	44.5[e]
(Scenario 2)	--	~65	~66	~57	~59

(a) Values include a 25% contingency.
(b) Values are in constant 1978 dollars.
(c) These reduced values result from lesser amounts of contaminated materials for burial in a licensed disposal site.
(d) Order of magnitude estimate, based on engineering judgement, applies only to entombment scenario 2.
(e) It is assumed that the entombed radioactive material decays to the unrestricted release level in 100 years.

2.11 OCCUPATIONAL AND PUBLIC SAFETY

Radiological and nonradiological safety impacts from normal decommissioning operations and from potential accidents are identified and evaluated for the reference BWR for the immediate dismantlement, passive safe storage with deferred dismantlement, and entombment decommissioning alternatives. The safety evaluation includes consideration of radiation dose to the public from normal operations and postulated accidents and from potential chemical pollutants. The safety evaluation utilizes current data and methodology, along with engineering judgment when necessary, to estimate the required input information and the resulting safety impacts. The approach used to evaluate all the safety aspects of a particular decommissioning activity is believed to be conservative.

The results of the safety evaluation of normal decommissioning operations are summarized in Table 2.11-1. The principal radiation dose to the public results from the transport of radioactive materials from the reactor station to disposal facilities. The estimated dose to the public resulting from decommissioning operations is extremely small.

TABLE 2.11-1. Summary of Safety Analysis for Decommissioning the Reference BWR

Type of Safety Concern	Source of Safety Concern	Units	Immediate Dismantlement	Entombment		Passive Safe Storage with Deferred Dismantlement After			
				(Scenario 1)	(Scenario 2)	10 Years	30 Years	50 Years	100 Years
Public Safety[a]									
Radiation Dose	Decommissioning Operations[b]	man-rem	0.05	0.04	0.04	<0.05	<0.05	<0.05	<0.05
	Transportation	man-rem	11	7.2	5.9	5.6	2.9	2.7	2.7
	Continuing Care	man-rem	--	neg.[c]	neg.[c]	neg.[c]	neg.[c]	neg.[c]	neg.[c]
Occupational Safety									
Serious Lost-time Injuries	Decommissioning Operations	total no.	6.7	6.5	6.5	9.6	9.6	9.6	9.6
	Transportation	total no.	1.2	0.8	<0.8	1.5	1.5	1.5	1.5
	Continuing Care	total no.	--	--	--	0.06	0.18	0.30	0.61
Fatalities	Decommissioning Operations	total no.	0.038	0.039	<0.039	0.058	0.058	0.058	0.058
	Transportation	total no.	0.072	0.047	<0.047	0.087	0.087	0.087	0.087
	Continuing Care	total no.	--	--	--	0.00061	0.0018	0.0031	0.0061
Radiation Dose	Decommissioning Operations	man-rem	1 845	1 684	1 573	871	418	388	386
	Transportation	man-rem	120	75	56	60	30	28	28
	Continuing Care	man-rem	--	--	--	1.3	6.5	10.0	10.0

(a) Radiation doses from postulated accidents are not included.
(b) 50-yr committed dose equivalent to the lung, for the total population within an 80-km radius of the site.
(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 decommissioning operations.

Less than 10 lost-time injuries from industrial-type accidents are predicted to occur during the decommissioning effort, with one additional injury predicted to result from transportation operations. Essentially no fatalities are predicted to occur as a result of decommissioning operations, including transportation.

2.12 COMPARISON WITH OTHER STUDIES

A review of four studies on decommissioning of BWR power stations (two from Germany, the 1976 AIF study, and a 1977 analysis by the Washington Public Power Supply System) shows that it is extremely difficult to compare these studies because the level of detail and the basic assumptions vary markedly between them. The cost estimates for immediate dismantlement from these studies range from $31 million to $100 million in 1978 dollars, with the two German studies estimating the highest costs.

2.13 FACILITATION OF DECOMMISSIONING

A number of techniques for facilitating decommissioning are presented and examined for their impact on cost and occupational radiation dose during reactor operation and maintenance, as well as during immediate dismantlement. It is concluded that the techniques that are most beneficial are those that reduce cost and radiation dose during operations and maintenance, since many more opportunities for reducing cost and dose occur over the operating life of the plant than occur during decommissioning.

2.14 IMPACTS OF ALTERNATE STUDY BASES

Analyses of the sensitivity of cost and radiation dose to such factors as plant size, radiation dose rate, disposal-site charges, etc., are developed and presented.

Scaling factors are developed for use in estimating costs and occupational radiation dose for decommissioning BWR power stations whose sizes are smaller than the reference BWR. An overall scaling factor (OSF) is derived that is a function of the plant power rating (PPR) in thermal megawatts:

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

The product of this scaling factor (evaluated for the power rating of the smaller plant) and the cost for decommissioning the reference BWR yields a reasonable estimate of the cost for decommissioning the smaller plant.

If the radiation dose rates throughout the reference plant are three times greater than assumed in this study, occupational radiation doses are estimated to more than double, and the cost of immediate dismantlement and entombment, if accomplished in the same manner as before, is estimated to increase by over $6 million. A more extensive chemical decontamination program would minimize the impact of higher initial radiation dose rates from piping and equipment.

The total decommissioning cost is not very sensitive to disposal rates at a shallow-land burial facility or at a deep geologic waste storage facility. Doubling the burial ground charges is estimated to increase the total decommissioning cost by less than 9%, and tripling the deep geologic disposal charges is estimated to increase the total decommissioning cost by about 6%.

The impact of the different containment structure designs (Mark I, II, and III) on decommissioning costs is estimated to be insignificant.

2.15 CONCLUSIONS AND RECOMMENDATIONS

Decommissioning of a large BWR power station is technically feasible with present-day technology. Further development of special equipment such as the plasma-arc torch, the arc saw, and sophisticated remote-handling equipment could lead to reductions in both cost and occupational radiation exposure.

Existing regulations appear to cover decommissioning. However, some modifications and/or additions that speak specifically to the requirements for decommissioning would be helpful. Centralization or an indexing of regulations that apply to decommissioning would also be helpful.

The estimated occupational radiation dose resulting from decommissioning is, at most, roughly equivalent to the dose resulting from about three or four typical refueling and maintenance outages, and thus does not appear to be prohibitively large. The impact of decommissioning on the safety of the public is small, with no significant risk to the public identified.

To put the various decommissioning alternatives in perspective, it is useful to examine the estimated costs and occupational radiation doses associated with achieving unrestricted release of the facility and the site. For the safe storage and entombment alternatives, it is assumed that the release takes place about 100 years after final reactor shutdown, The estimated cost and radiation dose for each alternative is given in Table 2.15-1. From the table it is seen that immediate dismantlement costs the least but results in the greatest radiation dose. Passive safe storage with deferred dismantlement has a significantly higher cost but a much reduced radiation dose. Neither of the entombment scenarios is a significant improvement over immediate dismantlement. The cost of having the property unavailable for unrestricted use for 100 years is not included in these comparisons, since the complexity of estimating that cost is beyond the scope of this study.

TABLE 2.15-1. Comparison of Costs and Radiation Dos[illegible] for Decommissioning the Reference BWR Via the Vari[illegible] [illegible]natives

Decommissioning Alternative	Cost (millions, 1978 dollars)	Occupational Radiation Dose (man-rem)[a]
Immediate Dismantlement	43.6	1 965
Passive Safe Storage	55.0[b,c]	414
Entombment		
(Scenario 1)	44,5[b,d]	1 759
(Scenario 2)	~59[b,c]	1 629

(a) Doses include decommissioning and transportation workers.
(b) Cost includes maintenance and surveillance for 100 years.
(c) Cost includes dismantlement after 100 years.
(d) No dismantlement assumed.

The acceptability of disposal of highly activated and/or long-lived radioactive materials by burial in a shallow-land burial facility is under consideration by the NRC and needs to be determined. If placement of these materials in a deep geologic disposal facility similar to that postulated for high-level radioactive wastes is required in the future, decommissioning costs will be increased by about $1 million.

If the bulk of the nonactivated, contaminated stainless steel and non-ferrous metals can be decontaminated to levels sufficiently low to permit unrestricted use, additional savings can be realized. However, the appropriate definitions of the amount of radioactivity that would be permitted on such materials when released for unrestricted use are not presently available.

Certain types of data useful to decommissioning analyses are essentially nonexistent at this time. Measurements on activated stainless steel that has been irradiated for an extended period of time (>10 years) to determine the growth of such long-lived radionuclides as ^{59}Ni and ^{94}Nb would be valuable for confirmation of calculations. Similarly, measurements of the growth of radionuclides in irradiated concrete would be helpful in evaluating the radiation dose rates that might be encountered from the activated reactor shield. In particular, the levels of ^{152}Eu and ^{154}Eu resulting from trace amounts of europium present in the concrete are important contributors to the total radiation dose rate from the concrete. In addition, studies to determine the actual levels of radioactivity on the soil surfaces surrounding operating reactor facilities would help to characterize in a realistic manner the residual radioactivity that might be present after 40 years of operation, and would help to quantify the decontamination effort that might be required to release the site for unrestricted use. Selected research programs in these areas are in progress sponsored by the NRC.

Careful attention during the design and construction phase of a reactor project to simplify the problems of eventual decommissio[illegible] would be effective in reducing decommissioning costs and occupational radiation exposure.