Nuclear Waste: Is There A Need For Federal Interim Storage?

Report of the Monitored Retrievable Storage Review Commission

November 1, 1989

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MONITORED RETRIEVABLE STORAGE REVIEW COMMISSION

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November 1, 1989

The Honorable Thomas S. Foley
Speaker of the House
United States House of Representatives
H-204 Capitol
Washington, D.C. 20515-6501

The Honorable Robert C. Byrd
President Pro Tempore
United States Senate
Hart Office Building, Suite 311
Washington, D.C. 20510-1902

Dear Speaker Foley and Senator Byrd:

The Monitored Retrievable Storage Review Commission herewith submits its final report as required by the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203, as amended by Public Law 100-507.

The Congress created the Commission to provide a report on the need for a Federal monitored retrievable storage facility (MRS) as part of the Nation's nuclear waste management system. In essence, Congress asked the Commission to review the U.S. Secretary of Energy's proposal to create an MRS, evaluate the technical need for an MRS, obtain data and comments from affected parties, and recommend whether such a facility should be included in the nuclear waste management system.

The Commission concludes that the MRS as presently described in the law, which links the capacity and schedule of operation of the MRS to a permanent geologic repository, cannot be justified. The Commission finds, however, that while no single factor would favor an MRS over the No-MRS option, cumulatively the advantages of an MRS would justify the building of an MRS if: (1) there were no linkages between the MRS and the repository; (2) the MRS could be constructed at an early date; and (3) the opening of the repository were delayed considerably beyond its presently scheduled date of operation.

The Commission notes that the Congress, for many years, has expressed concern that an unlinked MRS might be regarded as a de facto repository and could reduce the impetus for proceeding with permanent geologic disposal. The Commission recognizes this expression of Congressional will, as well as similar sentiments voiced during the course of its hearings. Although the Commission does not believe that there is a technical basis for the linkages, the Commission concludes that some linkages are justified.

Based on our studies, and the conclusions noted above, the Commission has decided that some limited interim storage facilities would be in the national interest to provide for emergencies and other contingencies. The Commission feels that such facilities would be especially desirable in light of delays which have already been experienced as well as additional delays that might be encountered in building a permanent geologic repository. The Commission therefore recommends that the Congress take the following actions:

1. Authorize construction of a Federal Emergency Storage (FES) facility with a capacity limit of 2,000 metric tons of uranium.

2. Authorize construction of a User-Funded Interim Storage (UFIS) facility with a capacity limit of 5,000 metric tons of uranium. Such a facility would provide only storage, and would be in addition to the FES.

3. Reconsider the subject of interim storage by the year 2000 to: (a) take into account uncertainties that exist today and that might be resolved or clarified within ten years; (b) consider developments that cannot be anticipated today; and (c) evaluate the experience with the two facilities recommended above.

The Commission believes that these recommendations, together with the analyses contained in the report, carry out the mandate given the Commission by the Congress.

We thank you for the opportunity to serve the Congress. It is our hope that the report will assist the Congress as it continues to deliberate on the management and disposal of the Nation's spent nuclear fuel. We stand ready to assist Congress in any way possible to accomplish this goal.

Sincerely,

Alex Radin

Alex Radin
Chairman

Dale Klein

Dale E. Klein
Commissioner

Frank L. Parker

Frank L. Parker
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MONITORED RETRIEVABLE STORAGE REVIEW COMMISSION

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Commission Activities

After being sworn into office on June 14, 1988, the Monitored Retrievable Storage (MRS) Review Commission members assembled and organized a small staff. The Commission operated as a collegial body, with commissioners intimately involved in directing the research and establishing the report writing methodology. From June 14, 1988, until November 1, 1989, the Commission met formally almost every other week. In addition, commissioners traveled individually to gather pertinent information.

All Commission meetings with outside persons or organizations were open to the public. Transcripts of public meetings and routine correspondence were available for review in a Public Document Room at the Commission's offices in Washington, D.C.

The Commission solicited the views of a broad spectrum of people and organizations by holding public hearings in Washington, D.C.; Denver, Colorado; San Francisco, California; and Atlanta, Georgia. (See Appendix A.) The hearings were well attended and produced a wealth of information and insights used during the Commission's deliberations. A total of 173 private citizens, nuclear waste experts, nuclear utility officials, State and local government representatives, Members of Congress, and representatives of citizen and environmental action groups testified, expressing a wide variety of views and, in many instances, submitting statements for the record. Commissioners listened to and questioned each witness concerning the rationale and long-term consequences of his or her recommendations. The Commission also received statements for the record from people unable to attend the hearings. (See Appendix B.)

Throughout its study, the Commission conducted public briefings to gather relevant information. (See Appendix C.) In July 1988, the U.S. Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), Members of Congress and their staffs, the General Accounting Office (GAO), the nuclear industry, the State of Tennessee, and environmental action groups briefed the Commission on monitored retrievable storage work done before the Commission was created.

In September 1988, the Commission requested a series of briefings on specific topics by DOE and NRC representatives. DOE presented information on its ongoing studies on the need for an MRS facility, rod consolidation, its dry cask storage study, and the status of the repository program. NRC briefed the Commission on its procedures for licensing independent spent fuel storage installations and certifying casks for transportation of spent nuclear fuel.

Soon after its formation, the Commission determined it needed to examine first-hand how utilities and others handle and store spent fuel. In October 1988, the Commissioners and the Commission's Executive Director visited Carolina Power and Light Company's H.B. Robinson Nuclear Project in Hartsville, South Carolina, and Virginia Power Company's Surry Nuclear Power Station in Surry, Virginia. Although these are the only U.S. commercial nuclear power plants currently using at-reactor dry storage facilities for spent fuel, other utilities are exploring the possibility. The facilities' handling and storage of spent fuel were examined, and the utilities' reasons for adopting this type of storage and their plans for the future were discussed.

In addition to those site visits, the Commissioners and Executive Director visited facilities in Sweden, the Federal Republic of Germany, France, and Switzerland to learn about the European experience with spent fuel storage and to examine possible components of an interim storage system. They observed many approaches to spent fuel management ranging from wet centralized storage of spent fuel at CLAB in Sweden to the dry centralized storage of vitrified high-level wastes from reprocessing at La Hague in France. (See Appendix D.)

Following this trip, the Commission held a public briefing in Washington, D.C., in November 1988, to obtain additional information from officials of COGEMA, a French nuclear fuel cycle company. Another briefing followed in December 1988 to obtain information from DOE on its program to construct a permanent repository for the disposal of nuclear waste. Department officials briefed the Commission on efforts to characterize the Yucca Mountain site in Nevada and the schedule for providing a permanent repository for high-level radioactive waste.

In March 1989, DOE provided the Commission with the preliminary results of its system studies on the need for an MRS facility. In May 1989, DOE supplied the final results of those studies and stated the department's current position on the need for an MRS facility. At the same meeting, NRC officials briefed the Commission on safeguards issues associated with a potential MRS facility.

The Commission's evaluation focused on a series of alternative waste management strategies. Acting on an early decision to contract for assistance to augment its staff efforts in performing needed complex analyses, initial contracts totaling $827,836 were awarded in February 1989 to perform five technical tasks and to provide data and analytical tools for the Commission to use in performing its evaluation. The same month, the Commission sent Congress and other interested parties a status report detailing Commission activities to date.

In March 1989, the Commission invited a group of experts to review a draft outline of the report. They represented a wide range of views pertaining to the nuclear waste issues the Commission was examining and provided their expert perspectives on the scope of the report.

Throughout the summer, the Commission received results of the contractors' work. Contractors' work, which included development of two computer models, augmented technical and public policy work already underway. (See Appendix E.) The Commission also received, in July 1989, the State of Tennessee's final study on the need for an MRS facility. In August, Edison Electric Institute submitted a study on the role of an MRS prepared by Energy Resources International at the request of the Edison Electric Institute/ Utility Nuclear Waste and Transportation Program. The Commission held a retreat in August to determine its conclusions and recommendations.

This report, completed during the remaining months of the Commission's existence, reflects the Commission's extensive technical work and public policy deliberations.

Executive Summary

About 20,000 metric tons of spent, or used, nuclear fuel have accumulated since the beginning of commercial nuclear power production in the United States. At the end of the currently licensed period of all existing nuclear power plants and those under construction, the amount of spent nuclear fuel is expected to total 87,000 metric tons.

Thus far, practically all of the spent nuclear fuel is stored in water-filled pools at reactor sites. However, space does not exist in the pools to store all the spent fuel expected to accumulate over the lifetime of the reactors. Therefore, other storage must be made available.

U.S. policy is to dispose of spent fuel from nuclear power plants in a permanent underground geologic repository. The objective of permanent disposal is to limit to safe quantities the amount of nuclear waste that might reach the biosphere during the next 10,000 years and beyond.

To achieve that objective, Congress, in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), designated Yucca Mountain, Nevada, as the candidate site for a repository. Final selection of the Yucca Mountain site was made subject to extensive studies of the suitability of this site and other conditions.

The objective of Congress in adopting the NWPAA was to have a repository available for accepting spent fuel in 1998. However, the U.S. Department of Energy (DOE), which has responsibility for characterizing the Yucca Mountain site, has announced that the opening of the repository will be delayed until 2003, and it is likely that there will be additional delays.

To store spent fuel until the permanent repository is available, a monitored retrievable storage (MRS) facility has been proposed by DOE. The MRS would serve as a means of collecting spent fuel, in excess of that in reactor pools, in a central location, where it would be stored until the fuel can be accepted at the repository. It has also been proposed that the MRS could serve other purposes, such as consolidating the fuel and packaging it for ultimate disposal in the repository.

Facilities similar to an MRS have been proposed since 1972 and have always been the subject of considerable controversy. As recently as 1987, DOE proposed to build an MRS at the Clinch River site near Oak Ridge, Tennessee. In adopting the NWPAA later that year, however, Congress "annulled and revoked" the DOE proposal to locate an MRS in Tennessee.

In the same law, Congress authorized the construction of an MRS but created the Monitored Retrievable Storage Review Commission to study and report to Congress on whether an MRS should be a part of the Nation's nuclear waste disposal system. Essentially, Congress directed the MRS Review Commission to compare the options of a waste disposal system that included an MRS with one that did not include an MRS. The latter, which is known as the No-MRS alternative, would require continued storage of spent nuclear fuel at the more than 70 existing sites of nuclear power plants until the repository is operational.

In the NWPAA, DOE was directed to begin site surveys for an MRS only after the MRS Review Commission had submitted its report to Congress. The NWPAA also limited the capacity of the MRS and linked its construction and operation to the repository schedule.

This report represents the results of almost 18 months of study and deliberations by the MRS Review Commission in response to its mandate from Congress. In addition to its own studies and evaluations, the Commission contracted a number of studies by independent consultants; held extensive public hearings in four locations in the United States; reviewed detailed studies by DOE, the State of Tennessee, and others; received numerous written statements; and visited nuclear waste storage sites in the United States and in four European countries.

As a result of its extensive studies and deliberations, the Commission reached the following conclusions:

Conclusion No. 1. From a technical perspective, both the No-MRS and MRS options are safe.

Although neither option is completely without risk, the Commission determined that the risks are expected to be small and within regulatory limits, and the degree of difference in risks is so small that the magnitude of difference should not affect the decision as to whether there should be an MRS.

Conclusion No. 2. The net cost of a waste management system that includes an MRS would be lower than previously estimated because of delays that have already occurred in the expected date of repository operation, and the likelihood of further slippages of that date.

The economics of an MRS would become more favorable if the repository were delayed and if the MRS were to accept spent fuel as early as possible. These effects would become especially significant if the repository operation were to be delayed beyond 2013, when there will be a sharp increase in the number of nuclear power plants whose current licenses will expire. If a repository were not in operation by that time, utilities would incur major additional costs that would result from the inability to remove spent fuel from plants being decommissioned. However, a system with an MRS would still be somewhat more costly on a discounted basis than one without an MRS.

Conclusion No. 3. There are no single discriminating factors that would cause the MRS alternative to be chosen in preference to the No-MRS alternative.

Although the Commission does not find any single factor that would cause it to favor one alternative, it believes that, cumulatively, there are a number of advantages that would justify a central storage facility not limited in capacity nor linked to the repository schedule and operation. These advantages include storage for emergency purposes; storage for utilities which do not have sufficient space in their spent fuel pools or on-site or which cannot obtain a license for additional at-reactor storage and, hence, might be required to shut down an otherwise satisfactorily operating nuclear power plant; storage for spent fuel from shutdown reactors; economies in the waste management system if an MRS could be completed substantially before the repository; greater redundancy in the system in the event of unforeseen circumstances; more surge capacity to facilitate the flow of spent fuel to the repository; more flexibility in storage options and future waste preparation functions; assistance in standardization; and initiating Federal responsibility for taking possession of spent fuel.

Conclusion No. 4. An MRS linked as provided in current law would not be justified, especially in light of uncertainties in the completion time for the repository. Consequently, the Commission does not recommend a linked MRS as required by current law and as proposed by DOE.

The Commission notes that Members of Congress, other public officials, environmental groups, and many private citizens for many years have expressed concern that an unlinked MRS might be regarded as a de facto repository, and thereby would reduce the impetus for building the repository as expeditiously as possible. Although the Commission does not believe that there is a technical basis for the linkages, the Commission agrees that, in light of congressional and other concerns about a de facto repository, some linkages are justified.

However, the schedule linkage presently in the NWPAA (MRS construction may not begin until the Nuclear Regulatory Commission issues a license for the construction of a repository) would make it impossible for an MRS to be operational more than three years before the repository. Because of delays already experienced in the repository schedule and continued uncertainty surrounding the repository's location and date of operation, the value of the MRS would be greatly diminished if its construction were tied to the schedule of the repository. Most of the need for an MRS would have disappeared, in that utilities would have had to make other arrangements for storage.

Conclusion No. 5. Some interim storage facilities, substantially more limited in capacity and built under different conditions than the DOE-proposed MRS, are in the national interest to provide for emergencies and other contingencies.

The Commission recognizes the need to provide certain services that would be in the national interest, but which could not be provided by an MRS restricted by the schedule linkages currently in the law. The Commission concludes that spent fuel storage for emergency and other purposes would be in the national interest. Facilities to fulfill this national interest could be more limited in scope and could be built under different conditions than the DOE-proposed MRS.

In view of the conclusions noted above, and in light of its extensive studies and deliberations, the Commission recommends the following:

Recommendation No. 1. Congress should authorize construction of a Federal Emergency Storage (FES) facility with a capacity limit of 2,000 metric tons of uranium (MTU).

In light of the continuing delay in the building of a repository, the Commission believes it would be in the national interest to have available a safety net of storage capacity for emergency purposes, such as an accident at a nuclear power plant, which would make it advantageous to have the plant's spent fuel pool available for decontamination of affected parts of reactors and for storage of debris.

If the facility proposed in Recommendation No. 2 were not available, the FES also could be used to store spent fuel from otherwise satisfactorily operating nuclear power plants that would have to be shut down because of insufficient on-site storage.

Because the FES would be designed primarily for emergency use and, hence, would serve as "insurance" for the entire industry, the Commission recommends that the cost of this facility should be paid from the Nuclear Waste Fund, to which all of the utilities which generate power from nuclear energy contribute.

Recommendation No. 2. Congress should authorize construction of a User-Funded Interim Storage (UFIS) facility with a capacity limit of 5,000 MTU. Such a facility would provide storage only, and would be used in addition to the Federal Emergency Storage facility proposed in Recommendation No. 1.

Although spent fuel can be stored safely at reactor sites for as long as 100 years, some utilities may not have space on-site for life-of-plant storage or may not be able to obtain a license for additional storage.

In view of the uncertainties regarding the availability of a repository, the Commission believes it would not be in the national interest to force utilities to shut down operation of otherwise satisfactorily operating nuclear power plants because of lack of storage capacity for spent fuel. Congress recognized this problem by authorizing, in Section 135 of the Nuclear Waste Policy Act of 1982, a Federal Interim Storage facility (FIS). It is the Commission's intention that the 5,000 metric ton storage facility that it recommends likewise should be available in such contingencies.

This facility also should provide storage for: (a) shutdown reactors at sites where a utility no longer operates nuclear power facilities, and (b) utilities which would prefer to ship spent fuel to this facility rather than retain it on-site.

In view of the uncertainties which have existed as to the time of operation of the MRS and the repository, many utilities with newer reactors have already taken steps to provide needed life-of-plant storage, while others have expressed a preference for providing such storage themselves rather than relying on an MRS. For these reasons, the Commission believes it would be more equitable for the storage facility (UFIS) to be user funded, so that only those utilities that chose to use the facility would pay for it.

Recommendation No. 3. Congress should reconsider the subject of interim storage by the year 2000 to: (a) take into account uncertainties that exist today and which might be resolved or clarified within 10 years, (b) consider developments which cannot be anticipated today, and (c) evaluate the experience with the two facilities recommended above.

Many uncertainties make it extremely difficult to plan for long-term interim storage of spent fuel. Although the opening of the repository is the most notable uncertainty, many other questions also must be resolved.

The Commission believes that the actions recommended above should be adequate to take care of the needs of interim storage at least until the year 2006. However, by the year 2000, Congress should reconsider the question of interim storage of spent fuel. At that time, Congress should take into account, among other things, such factors as: status of the repository; status of nuclear power plants; availability of at-reactor storage; utilization and adequacy of the 2,000 metric ton Federal Emergency Storage facility and the 5,000 metric ton User-Funded Interim Storage facility; status of technological developments in the storage of spent fuel; nuclear waste system optimization; and the fee schedule established for the UFIS.

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The Monitored Retrievable Storage Review Commission believes that these recommendations would provide safe interim storage of spent nuclear fuel, would be consistent with the goals of the national nuclear waste management system, and would provide for flexibility and unforeseen contingencies.

Chapter One
Introduction

Nuclear power plants generated about 19.5 percent of all electricity produced in the United States in 1988.[1] These plants generate electricity through the fission (splitting of atoms) of uranium-235 fuel, which is contained inside a zirconium alloy rod. As the fuel fissions and generates heat to produce power, fissile uranium-235 is depleted, and the efficiency of the chain reaction decreases. After three or four years of use, the spent (that is, partially depleted) fuel rods have to be removed from the reactor and replaced with new ones. The spent fuel rods are highly radioactive and must be isolated from people and the environment. The United States regulates and treats spent fuel as high-level radioactive waste (HLW).[2]

About 20,000 metric tons of commercial spent nuclear fuel is now stored at more than 70 nuclear power plant sites around the country. (See Figure 1.1.) Most of the spent fuel is now stored in pools. It is expected that existing nuclear power plants will produce approximately 87,000 metric tons of spent fuel during their lifetimes.[3]

The spent fuel is small in volume compared to other hazardous materials but is highly radioactive. It produces heat and remains hazardous for more than 10,000 years. Therefore, the spent fuel must be handled carefully. It can be reprocessed, stored, or disposed of permanently by isolating it from the environment for thousands of years. U.S. policy is to dispose of spent fuel by isolating it from the environment in an underground, geologic repository. Other nations also plan to construct geologic repositories, but most nations plan to store spent fuel or waste from reprocessing for many years before eventual disposal.[4]

Under the Nuclear Waste Policy Act of 1982 (NWPA),[5] the Congress required electric utilities generating power at nuclear plants to pay into a Nuclear Waste Fund to cover the costs of storage and disposal of spent nuclear fuel. Thus far, more than $4 billion has accumulated in this fund, which is administered by the Department of Energy (DOE). Contributions to this fund, which are ultimately paid by electric consumers, are now based on a charge of 1 mill (one-tenth of a cent) for each net kilowatt-hour of electricity produced by nuclear power plants.

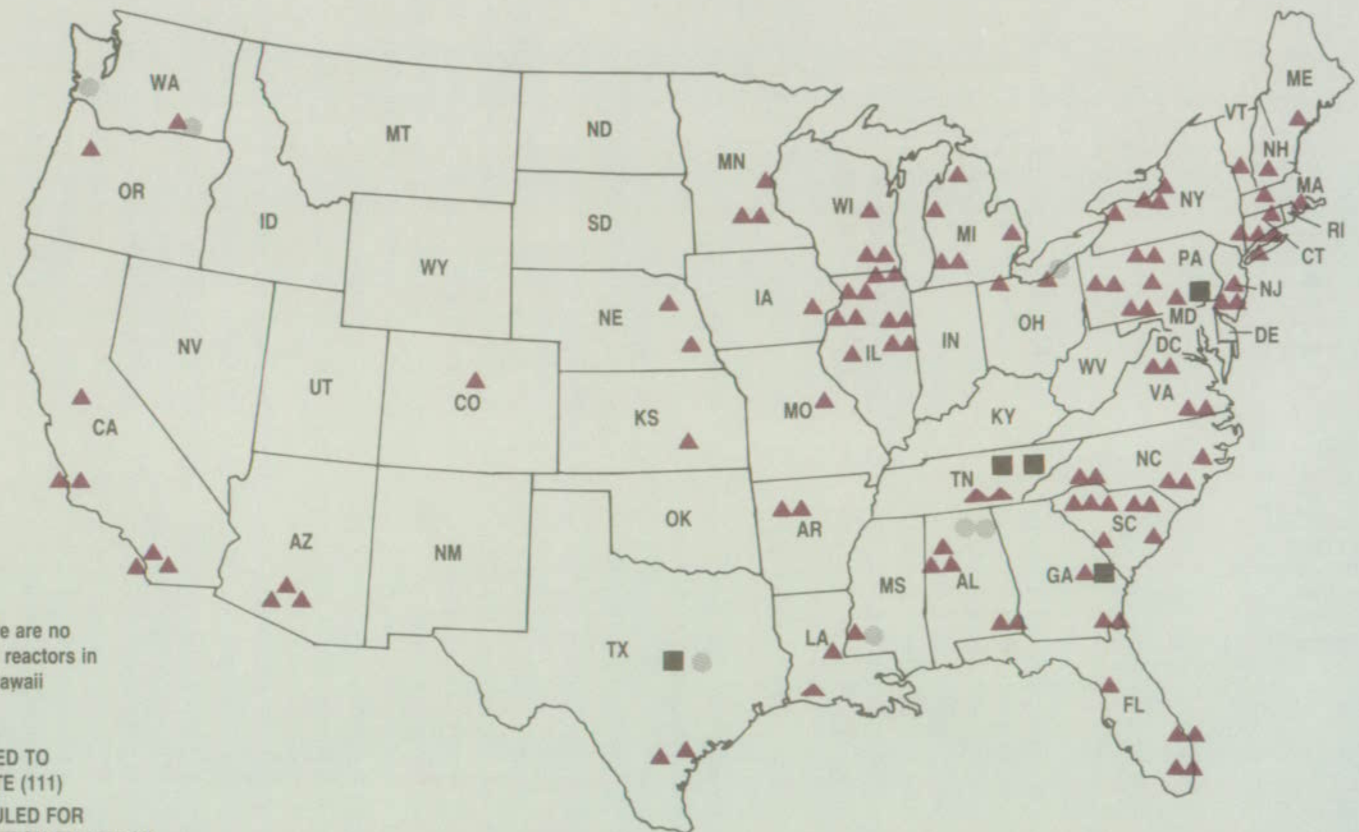
Under current law, DOE was expected to begin to take possession of the spent fuel in 1998 and, ultimately, to dispose of the waste in an underground repository. However, the program to develop a repository to receive the spent fuel for safe disposal is technically, institutionally, and politically complex. Consequently, according to DOE's estimates as of May 1989, it is unlikely a repository will be available before the year 2003.[6] Other experts believe a repository may not be ready to accept spent fuel until considerably later.

Thus, the question facing the country is: What should be done with the spent fuel accumulating at more than 70 nuclear reactor sites around the country until it can be disposed of in a permanent repository?

The Congress has grappled with this issue for some time. Some Members of Congress believe the waste should be left at the reactors until a permanent repository is built. Other Members, and the Department of Energy, believe DOE should collect spent fuel from the nuclear power plants and store it in a central, Federal facility before disposal. The term now used for such a facility is "monitored retrievable storage facility" (MRS).

In 1985, DOE proposed to construct an MRS at one of three sites in Tennessee and recommended the Clinch River site. The proposed facility would perform the functions of storage, rod consolidation, packaging, and gathering spent fuel for shipment to the repository. In the ensuing debate over DOE's proposal, Congress created the MRS Review Commission to evaluate the department's proposal and to make a recommendation on the Nation's need for a monitored retrievable storage facility as part of its nuclear waste management system.

Figure 1.1—U.S. Commercial Nuclear Power Reactor Sites



NOTE: There are no commercial reactors in Alaska or Hawaii

LEGEND
▲ LICENSED TO OPERATE (111)
■ SCHEDULED FOR COMPLETION BY 1995 (5)
● DEFERRED CONSTRUCTION (7)

SOURCE: NRC 1/31/89

Section One: The Commission's Mandate

Congress created the MRS Review Commission in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA),[7] directing the Commission to prepare a report on the need for an MRS as a part of a national nuclear waste management system. The need for an MRS also must be considered in the broader context of the Nation's need to develop "safe and environmentally acceptable methods of disposal."[8] Congress specifically directed the Commission to compare storing spent fuel at an MRS to storing spent fuel at reactor sites before permanent disposal in a repository.[9] (See Figure 1.2.)

In May 1988, the Department of Energy initiated nine system studies to help the MRS Review Commission in its evaluation. The studies were presented to the Commission in May 1989, along with DOE's latest position on the need for a monitored retrievable storage facility. In contrast to its 1985 proposal, DOE's current proposal includes neither rod consolidation nor packaging functions, although DOE contemplated that the MRS might ultimately perform some of these functions. It is this current DOE position on which the Commission focused in response to its charge to "review the status and adequacy of the [Energy] Secretary's evaluation of the system's advantages and disadvantages of bringing such a facility into the national nuclear waste disposal system."[10]

Figure 1.2—The Commission's Charge

The MRS Commission shall:

(i) review the status and adequacy of the [Energy] Secretary's evaluation of the system's advantages and disadvantages of bringing such a facility into the national nuclear waste disposal system;

(ii) obtain comment and available data on monitored retrievable storage from affected parties, including States containing potentially acceptable sites;

(iii) evaluate the utility of a monitored retrievable storage facility from a technical perspective; and

(iv) make a recommendation to Congress as to whether such a facility should be included in the national nuclear waste management system in order to achieve the purposes of this chapter, including meeting needs for packaging and handling of spent nuclear fuel, improving the flexibility of the repository development schedule, and providing temporary storage of spent nuclear fuel accepted for disposal.

. . . The Commission shall compare such a [monitored retrievable storage] facility to the alternative of at-reactor storage of spent nuclear fuel prior to disposal of such fuel in a respoitory under this chapter. Such comparison shall take into consideration the impact on—

(A) repository design and construction;
(B) waste package design, fabrication and standardization;
(C) waste preparation;
(D) waste transportation systems;
(E) the reliability of the national system for the disposal of radioactive waste;
(F) the ability of the Secretary to fulfill contractual commitments of the Department [of Energy] under this Act to accept spent nuclear fuel for disposal; and
(G) economic factors, including the impact on the costs likely to be imposed on ratepayers of the Nation's electric utilities for temporary at-reactor storage of spent nuclear fuel prior to final disposal in a repository, as well as the costs likely to be imposed on ratepayers of the Nation's electric utilities in building and operating such a facility.

42 U.S.C. § 10163

Section Two: The Legal and Historical Context

The concept of Federal monitored retrievable storage of spent fuel is not new. Appendix F gives a detailed chronology of the evolution of the concept. Monitored retrievable storage first surfaced in 1972 after the Atomic Energy Commission (AEC) abandoned plans for a repository near Lyons, Kansas. To fill the void this abandonment created, the AEC proposed aboveground structures called Retrievable Surface Storage Facilities (RSSFs) for long-term interim storage until a permanent repository was available. The Environmental Protection Agency (EPA) and others severely criticized a 1974 AEC draft environmental impact statement on RSSFs because of concern that the facilities could become low-budget, permanent repository sites.[11] The RSSF proposal was withdrawn in 1975.

In 1977, the need for interim storage became more pressing because of President Carter's decision to defer commercial reprocessing of spent fuel as part of his nonproliferation of nuclear weapons policy.[12] With U.S. reprocessing indefinitely suspended, the President proposed that the Federal government take title to spent fuel, which would be transported at utilities' expense to a Federal away-from-reactor (AFR) facility for storage until a repository became available.[13] In his nuclear waste policy announced in February 1980, the President included an AFR with more limited capacity than was originally proposed. Such an AFR was intended to provide interim storage for utility spent fuel.[14]

In 1981, the Reagan administration lifted the reprocessing deferral and withdrew the away-from-reactor storage proposal.[15] However, the MRS concept played an important role in the comprehensive nuclear waste legislation then pending before Congress.

In the Nuclear Waste Policy Act of 1982, Congress attempted to create a stable institutional framework for managing the waste generated by the Nation's civilian nuclear power reactors. The act gave geologic disposal highest priority and set forth elaborate procedures and an ambitious schedule for siting, constructing, and operating two permanent geologic repositories.

The statute directed DOE to submit to Congress a detailed study of the need for and feasibility of a monitored retrievable storage facility in the national nuclear waste management system, as well as a proposal for constructing one or more MRS facilities.[16] The act envisioned an MRS that would: provide back-up storage of spent fuel and high-level waste from civilian nuclear activities; allow for continuous monitoring, management, and maintenance of spent fuel for the foreseeable future; permit ready retrieval of the spent fuel for reprocessing or disposal; and safely store the spent fuel for as long as necessary (a time limit was not specified).[17]

In 1985, DOE completed its study of the need for and feasibility of an MRS facility in the national program and greatly modified the concept of what an MRS facility should be.[18] Rather than a backup to the repository, the MRS was conceived as an integral part of an "improved performance" waste management system.[19] The MRS would be used for consolidating, repackaging, and storing the waste until the repository was ready.

In a companion study to the need and feasibility study, DOE proposed three MRS sites, all in Tennessee.[20] The State of Tennessee sued DOE in Federal court to block submission to Congress of DOE's proposal to site the facility in Tennessee. Tennessee argued that the NWPA required the department to consult with the State before choosing specific MRS sites. The court agreed with the State and issued an injunction preventing DOE from submitting its proposal to Congress.[21] However, the United States Court of Appeals reversed the lower court's decision, the Supreme Court refused to hear the case,[22] and DOE submitted its proposal to Congress on March 31, 1987.[23]

In December 1987, Congress passed the Nuclear Waste Policy Amendments Act of 1987, reaffirming the repository program as the primary focus of the Federal waste management effort. The act directed DOE to terminate all site-specific activities (other than reclamation) at all candidate repository sites other than the Yucca Mountain site in Nevada (that is, at sites in Washington and Texas) and all initial site investigations for a possible second repository. The NWPAA also "annulled and revoked" DOE's proposal to locate an MRS at any of the three proposed sites in Tennessee.[24] The legislation authorized an MRS, but directed DOE to begin site surveys only after the MRS Review Commission submitted its report to the Congress. Furthermore, the statute included certain conditions, to be incorporated in any MRS license issued by the NRC, that limit the capacity of the MRS and closely link its construction and operation to the repository schedule.[25] (See Figure 1.3.) Thus, under current law, the prospects for successfully siting and constructing an MRS are closely linked to the repository project's progress. This linkage is a significant consideration in evaluating the need for and usefulness of an MRS.

Figure 1.3—Nuclear Waste Policy Amendments Act Linkages

(1) construction of such facility [MRS] may not begin until the Commission [NRC] has issued a license for the construction of a repository under section 10135(d);

(2) construction of such facility or acceptance of spent nuclear fuel or high-level radioactive waste shall be prohibited during such time as the repository license is revoked by the Commission or construction of the repository ceases;

(3) the quantity of spent nuclear fuel or high-level radioactive waste at the site of such facility at any one time may not exceed 10,000 metric tons of heavy metal until a repository under this chapter first accepts spent nuclear fuel or solidified high-level radioactive waste; and

(4) the quantity of spent nuclear fuel or high-level radioactive waste at the site of such facility at any one time may not exceed 15,000 metric tons of heavy metal.

42 U.S.C. § 10168(d)

Section Three: The Problem

The question before the Commission is: Given that it is national policy to dispose of spent fuel from civilian reactors in a permanent geologic repository, what is the most appropriate way to store that fuel as it accumulates before repository operations start? While there are many options, there are two basic alternatives: (1) continue storing all spent fuel at the reactors where the spent fuel is generated; that is, the No-MRS alternative, and (2) store some spent fuel at a central location or locations as well as at some reactors; that is, the MRS alternative. The Commission examined each alternative's merits to determine an interim storage strategy which, to the extent practicable, maximizes the safety and effectiveness of the overall waste management system and increases the probability of attaining the national goal of permanent disposal.

Section Four: The Commission's Process

The question of the need for monitored retrievable storage is complex, controversial, and subjective, involving assumptions and expectations about future events, technical and political. There are deeply felt views on all sides of the issue.

Chapter Two describes the public policy context in which the issue has been examined, the major arguments for and against an MRS, and the issues which the Commission decided were most important in choosing between having and not having an MRS.

Chapter Three explains the Commission's analytical methods and assumptions. It describes the three base cases the Commission evaluated: (1) having no MRS; (2) having an MRS linked to a repository schedule as specified in the NWPAA; and (3) having an MRS unlinked to a repository schedule and not limited in capacity. Chapter Three also describes (1) the two computer modeling tools the Commission used to analyze the base cases; (2) a set of detailed assumptions about how spent fuel will be handled and transported that are needed to define the base cases; and (3) the variations or "sensitivity analyses" on the base cases that were examined.

Chapter Four compares the base cases by analyzing the relative effects on health, safety, and the environment.

It estimates the radiological dose to workers and the general public from each alternative. It considers the likelihood of a series of risks to public safety and the environmental and socioeconomic effects of each alternative.

Chapter Five compares the base cases by analyzing how safely spent fuel could be transported and handled. It compares the radiological effects and non-radiological (traffic accident) risks posed by spent fuel transportation as it would be conducted if there were an MRS and if there were not. It examines the risks of various spent fuel handling and packaging methods (such as dual-purpose casks, rod consolidation, and transshipment).

Chapter Six analyzes how the total system costs of the base cases would vary under the assumptions as to when the repository would begin to operate. The costs for each case and its principal cost components are estimated and the uncertainty inherent in the estimates discussed. The costs are analyzed in both nominal (undiscounted) value and present (discounted) value terms.

Chapter Seven discusses the distribution of costs and benefits among ratepayers, taxpayers, and stockholders as well as among governmental jurisdictions and geographic regions. It describes the types of costs imposed and some of the mechanisms available to adjust or compensate for those costs, should that be desirable. This chapter also includes a discussion of the appropriateness of user funding of various components of the spent fuel management and disposal system as opposed to paying for all costs from the Nuclear Waste Fund.

Chapter Eight describes the major policy advantages and disadvantages of an MRS, while concentrating on DOE's and the State of Tennessee's positions. The chapter concludes with a summary of the Commission's findings on the major advantages and disadvantages of an MRS.

Chapter Nine contains the Commission's conclusions and recommendations.

Chapter One Notes

1. Department of Energy, Energy Information Administration, "Commercial Nuclear Power 1989," DOE/EIA-0438(89) **(Hereafter cited as DOE/EIA-0438(89))**, p. ix.

2. In this report, the terms "spent fuel" and "waste" are used interchangeably. High-level waste is the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste, that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

3. Department of Energy, MRS System Study Summary Report, DOE/RW-0235, June 1989 **(Hereafter cited as Task J)**, Appendix B, p. 6.

4. See Appendix D for a detailed discussion of how other nations are handling spent fuel. The experience of these countries provides useful insights, but does not have any single clear message for U.S. spent fuel storage policy. The United States must make its decisions in a situation that is very different in a number of important aspects: in the absolute size (much larger) and relative importance (generally smaller) of its nuclear power program; in the regulatory, institutional, and political environment for nuclear power and waste management; in the pressures to develop a permanent repository and the related concerns that central storage facilities would delay that goal; and in the geographic characteristics (e.g., transportation distances, population densities, and the range of options available for siting storage and disposal facilities) that must be taken into account in waste management policy.

5. 42 U.S.C. § 10101 *et. seq.* (January 7, 1983).

6. Isaacs, Thomas H., Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE Position on the Monitored Retrievable Storage (MRS) Facility," Prepared Remarks before the Monitored Retrievable Storage Review Commission, May 25, 1989, p. 4; Task J, p. 69.

7. Pub. L. No. 100-203, 101 Stat. 1330-232 (December 22, 1987)(codified as amended in scattered sections of 42 U.S.C.).

8. 42 U.S.C. § 10131(a)(1).

9. Storage, as defined in the Nuclear Waste Policy Act, is the retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal. 42 U.S.C. § 10101(2)(25). Disposal, as defined in the Nuclear Waste Policy Act, is the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste. 42 U.S.C. § 10101(2)(9).

10. 42 U.S.C. § 10163(a)(1)(C)(i).

11. Office of Technology Assessment, U.S. Congress, *Managing the Nation's Commercial High-Level Radioactive Waste*, New York: UNIPUB, 1985 (OTA, 1985), p. 85.

12. *Public Papers of the Presidents*, Jimmy Carter, April 17, 1977, Book 1, pp. 582–583. Spent fuel contains usable fissile material (U-235 and Pu-239) which can be recovered by chemically reprocessing the fuel and used in recycled fuel. Reprocessing to recycle the fuel is now being done in countries such as France, the Federal Republic of Germany (FRG), the United Kingdom, and Japan. In 1977, President Carter announced the indefinite deferral of reprocessing of commercial spent fuel because of concerns regarding nuclear weapons proliferation. Although President Reagan lifted the suspension of commercial reprocessing in 1981, it is not currently viewed as economical in the United States and is not being done here.

Spent fuel from weapons reactors in the United States is reprocessed to recover plutonium for nuclear weapons. The waste from this reprocessing, now being stored as a liquid, will be solidified and disposed of in the same geologic repository as commercial spent fuel. Present projections of the medium potential for the production of defense high-level waste are between 9,500 and 33,900 canisters or 4,750-16,950 MTU. Oak Ridge National Laboratory, "Integrated Data Base for 1988; Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 4, September 1988, p. 54. (This is based on an estimate of 0.5 MTU of defense high-level waste per canister.) Kerrisk, J. F., "An Assessment of the Important Radionuclides in Nuclear Waste," October 1985, pp. 3–4.

13. OTA, 1985, p. 87.

14. *Public Papers of the Presidents*, Jimmy Carter, February 12, 1980, Book 1, pp. 296–301.

15. OTA, 1985, p. 88.

16. 42 U.S.C. § 10161.

17. 42 U.S.C. § 10161(b).

18. Department of Energy, "The Need For and Feasibility of Monitored Retrievable Storage—A Preliminary Analysis," DOE/RW-0022, April 1985.

19. Department of Energy, "Mission Plan for the Civilian Radioactive Waste Management Program," Vol. 1, DOE/RW-0005, June 1985, pp. 122-126.

20. Department of Energy, "Screening and Identification of Sites for a Proposed Monitored Retrievable Storage Facility," DOE/RW-0023, April 1985.

21. *Tennessee v. Herrington*, 626 F. Supp. 1345 (M.D. Tenn. 1986).

22. *Tennessee v. Herrington*, 806 F. 2d 642 (6th Cir. 1986), *cert. denied*, 480 U.S. 946 (March 30, 1987).

23. Department of Energy, "Monitored Retrievable Storage Submission to Congress," DOE/RW-0035/1-Rev. 1, March 1987.

24. 42 U.S.C. § 10162.

25. These statutory provisions refer to both spent fuel and high-level radioactive waste. However, the Commission has interpreted its mandate to be limited to wastes from the civilian reactor program. Defense wastes will not be addressed in this report. Storage facilities for vitrified defense wastes are being constructed at the sites of the vitrification plants.

Chapter Two
Key Issues

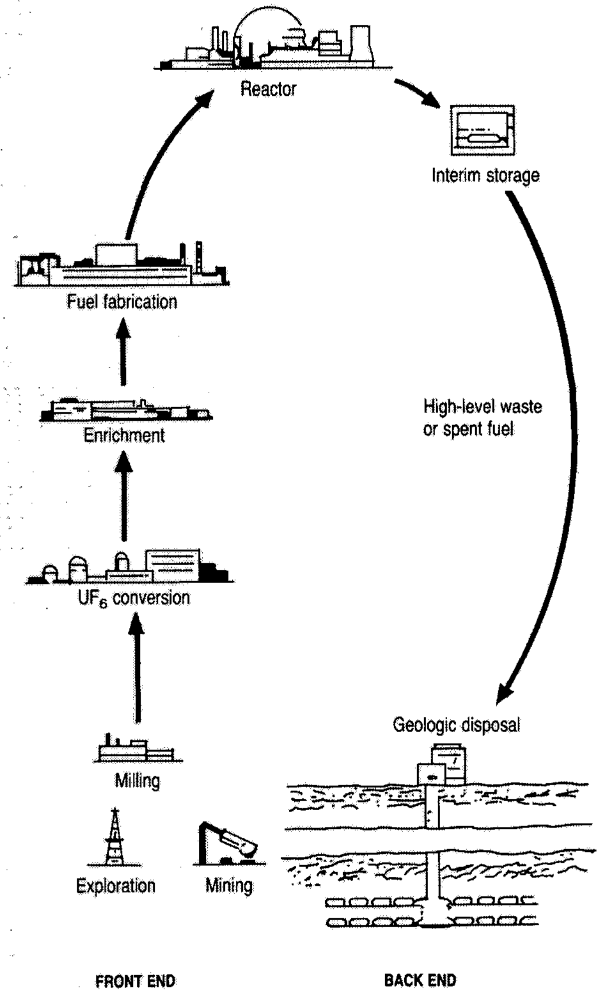
How to manage and dispose of spent nuclear fuel prudently and safely has proven to be a difficult, contentious public policy issue. It involves many technical and scientific uncertainties as well as public policy judgments about which fair and informed people have legitimate differences of opinion.

During its deliberations, the Commission held public meetings to hear the views of the public and government officials on the need for Federal monitored retrievable storage.[1] Wide-ranging views were expressed by Members of Congress, private citizens, representatives of citizen and environmental action groups, nuclear waste experts, managers of nuclear utilities, and governmental representatives at the Federal, State, and local levels. The Department of Energy (DOE) testified three times that an MRS is needed as an integral part of the Nation's nuclear waste management system.[2] With few exceptions, persons expressing views to the Commission supported construction of a permanent repository regardless of whether an MRS is built.[3] The MRS, if built, could be a part of the nuclear fuel cycle as shown in Figure 2.1.

The Commission studied all of the testimony presented during its public meetings and all of the statements submitted for the record. It became apparent that the Commission would be unable to address all topics that might in some way relate to the need for an MRS. Some, like storage of defense wastes, were beyond the Commission's mandate. Others, like the suggestion that spent fuel could be shipped to Europe for storage and reprocessing, were too speculative to merit serious consideration at this time. Therefore, the Commission decided to organize the most important issues into five categories for study: (a) health, safety, and environmental effects, (b) transportation safety, (c) economic costs and benefits, (d) distributional and equity concerns, and (e) policy considerations.

Section One of this chapter describes the public policy context of the MRS debate. Section Two categorizes and summarizes the primary arguments presented to the Commission for and against an MRS in each of the five study categories. Section Three lists the key questions that needed to be answered before the Commission could make an informed recommendation.

Figure 2.1—The Nuclear Fuel Cycle



SOURCE: U.S. Office of Technology Assessment
(Adapted from chart in *Managing the Nation's Commercial High-active Radioactive Waste*)

Section One: Public Policy Context

Few, if any, public policy issues have as long a planning horizon as nuclear waste disposal. The objective of permanent disposal is to limit to safe quantities the amount of nuclear waste that will reach the biosphere during the next 10,000 years and beyond. To put this objective in perspective, a planning horizon of 10,000 years dwarfs the lifespan of the world's recorded civilizations and political entities. Moreover, the United States' goal is to achieve permanent disposal within a single generation.

A time horizon of this length means that geologic stability and dynamics must be understood more completely than for any previously built facility. Choosing a location for a nuclear waste facility requires extensive site characterization and complex technical evaluation; these studies themselves take years and they may be complicated and delayed by political and policy issues, such as a community's response to siting plans. Despite the considerable time and money already expended to site a repository, none has been sited yet, and the date by which a permanent repository will be available is uncertain.

The purpose of building an MRS would be to store spent fuel from the time it is produced at reactors until it can be emplaced in a repository. The date when a permanent repository is likely to become operable and the debates surrounding that date are very important considerations in determining the need for an MRS.

The nuclear waste disposal debate has served as a proxy for the more fundamental debate about the merits of nuclear power technology. Critics argue that nuclear power should not be pursued unless a solution to the nuclear waste disposal problem is found.[4] Many environmental activists and other concerned citizens view effective nuclear waste disposal as a major moral imperative facing this generation. The risks of nuclear waste loom large in the environmental activists' view because some of the harmful materials have an extremely long life, and the costs of isolating them from the biosphere are high. Environmental activists assert that this generation has an ethical responsibility to guarantee that today's radioactive waste will not harm succeeding generations.[5]

For nuclear proponents, demonstrating the ability to manage and dispose of nuclear waste safely will validate the use of nuclear power. Supporters of nuclear power, and many members of the scientific community, believe nuclear waste can be managed and disposed of safely, but they are frustrated because large amounts of money, time, and resources have been dedicated to solving the problem with little apparent progress.[6]

Regardless of one's views on the merits of nuclear power, about 20,000 metric tons of spent fuel already exist at the reactor sites and must be stored somewhere. The Commission's charge is to evaluate objectively and systematically the alternatives for interim storage of spent fuel as part of the Nation's nuclear waste disposal system. Thus, this evaluation is structured around the specific arguments which have been made for and against an MRS.

Section Two: Summary of the Key Issues

This section summarizes the testimony presented to the Commission in each of the five study categories. Table 2.1 lists the main arguments in each category for and against building an MRS facility. The remainder of the section explains these arguments more fully.

A. Health, Safety, and Environmental Effects

Public health and safety and environmental protection are serious concerns of the American people and are of highest priority to the Commission.

1. Arguments for an MRS

Supporters emphasize that the technology is safe: the MRS poses no significant hazards to public health and safety, or the environment; and the risks associated with the MRS are similar to those of at-reactor storage.[7] Proponents assert that an MRS facility will reduce the interference that at-reactor storage poses for reactor operations, allowing utilities to focus attention on their primary responsibility: safe and reliable generation of electricity.[8] DOE and the utilities also argue that early and adequate

Table 2.1—Major Arguments Presented to the Commission For and Against an MRS Facility

Category	For MRS	Against MRS
Health, Safety, and Environment	Technology is safe	Will be more of a terrorist target
	Reduces interference with reactor operations	Fuel is already stored safely at reactors, so unnecessary
	Prevents delay in decommissioning	
Transportation Impacts	Consolidates routes to permanent site, limiting states/localities affected	Means additional handling and subsequent increase in risk
	Early decision needed to plan for emergencies a long routes	
Economic Costs and Benefits	If more expensive overall, benefits outweigh costs	Too expensive
	May not be more expensive overall if repository delayed and the cost to reactors of delaying decommissioning is considered	Benefits do not outweigh costs
		At-reactor storage cheaper
	Reduces at-reactor storage costs	No reductions in at-reactor costs because MRS cannot be built in time
	Generates economies of scale for packaging and handling	Enhanced transportation strategies are less expensive than an MRS
Distributional and Equity Concerns	Generates regional equity because only disposal site is currently in West	Makes western utilities pay for an MRS they may not use
	Risks, costs, stigma of being a high-level waste site would be shared	Makes utilities with extensive at-reactor storage pay twice—for at-reactor storage and an MRS
		Unfair to ratepayers to pay for an MRS which is more expensive than No-MRS.
Policy Considerations	Enables DOE to meet its contractual commitment for early acceptance	Federal government is not obligated to begin accepting spent fuel in 1998 if there are compelling reasons to delay or cancel an MRS facility
	Utilities will end up paying more for at-reactor storage unless DOE fulfills its contract	Congress can change commitment
	Provides valuable experience for siting repository	Will become a de facto repository; linkages with repository should be strengthened
	More beneficial if NWPAA linkages are removed	Will divert critical resources from repository
	Provides system flexibility to adapt to an uncertain future	Uncertainties in siting and developing an MRS
	Timely siting and construction needed to maximize MRS usefulness	System bottlenecks less likely to occur with at-reactor for storage

waste acceptance will ensure that spent fuel is removed from reactors without delaying planned decontamination and decommissioning.[9]

2. Arguments against an MRS

Several witnesses asserted that an MRS will increase risks to public health and safety, and impacts on the environment. They believe that spent fuel is being stored safely at reactors and can continue to be safely stored there until a repository becomes available. Some feel an MRS increases the risk of terrorist attacks because an MRS may require more shipments. They fear that collecting a large volume of spent fuel in a central location will provide a tempting target for terrorism.[10]

B. Transportation Impacts

Most State and local government representatives, while taking no position on an MRS, raise concerns about the transportation of spent fuel through their regions and inadequate emergency response capabilities along the routes. They stress the need for an early decision on an MRS to allow sufficient time for planning and emergency response training along proposed routes.

1. Arguments for an MRS

Some proponents suggest that consolidating spent fuel and using dedicated trains from the MRS to the permanent disposal site will reduce transportation impacts. DOE subscribed to this view in 1987 but has since concluded that transportation impacts are not a discriminator between MRS and No-MRS options, because actual transportation risks are extremely low.[11] DOE currently believes that an MRS will offer transportation advantages because the MRS would consolidate routes to the permanent disposal site, thus limiting the number of States and localities affected, as well as their need to be prepared for an emergency.

2. Arguments against an MRS

Substantial public apprehension exists over potential radioactive transportation accidents. Many argue that an MRS means additional handling and transportation of spent fuel, thereby significantly increasing the risk of radioactive contamination to people and property.[12] The State of Tennessee asserts that using dual-purpose casks and transporting spent fuel directly from the reactors to the repository would reduce handling and transportation impacts.[13]

C. Economic Costs and Benefits

The costs and benefits of an MRS would accrue to utilities and their ratepayers.

1. Arguments for an MRS

Proponents suggest that an MRS facility would provide benefits by generating economies of scale for spent fuel storage and packaging. Also, early acceptance of waste at an MRS will limit utility expenses for storing additional waste in and outside reactor pools.[14] Utility representatives assert that an MRS facility will reduce the costs and complexities of on-site storage of spent fuel, yielding significant savings to ratepayers.[15] Utilities are frustrated because the Federal government's waste management program has consumed large amounts of money but has shown little progress.

DOE indicates that an MRS facility will add between $1.3 billion and just over $2 billion to the cost of the national spent fuel management and disposal system. The costs cited are "net," meaning savings at reactors are taken into account. DOE points out that the earlier the MRS becomes operational, the greater the reduction in utility at-reactor storage costs, and the lower the net cost to the system.[16]

DOE argues that additional costs are justified by the advantages of building an MRS facility. DOE notes that the department's cost estimates do not take into consideration the potentially significant cost to reactors of delaying decommissioning if the opening of the repository is delayed.[17]

2. Arguments against an MRS

Opponents of an MRS assert that it is too expensive and that the potential benefits of incorporating the facility into the nuclear waste management system do not justify the costs. The State of Tennessee asserts that an optimized No-MRS strategy, using dual-purpose casks, would be $1 billion to $5 billion cheaper than a system with an MRS.[18] Some MRS opponents believe that the costs of an MRS will escalate well beyond DOE's current estimates, as has been the case with the costs of other nuclear facilities.

Some nuclear industry representatives do not favor an MRS. They point out that on-site storage would be cheaper than having an MRS in the system.[19] They conclude that continual slippage in DOE's schedule for opening the repository makes it highly unlikely an MRS will be sited and constructed within a reasonable time, especially in view of the linkages between the repository and an MRS. These nuclear industry representatives assert many utilities will not experience the reductions in on-site storage costs claimed by MRS proponents. They say it will be more cost effective in the long run to store the wastes at reactor sites while moving as expeditiously as possible to construct a permanent repository.

D. Distributional and Equity Concerns

Siting an MRS in the East would affect the geographic distribution of the costs and benefits of the Nation's waste management system.

1. Arguments for an MRS

The NWPAA directs DOE to limit its characterization of repository sites to Nevada's Yucca Mountain. Some contend that the process for making this determination was biased and unfair, and that Congress singled out Nevada for the repository because Nevada, with only two representatives in the House of Representatives, did not have enough influence in Congress. Consequently, Nevadans have to bear the burden of perceived risks, costs, and stigma associated with the nuclear repository. Some believe, therefore, that the burdens associated with hosting a nuclear waste site should be shared by placing an MRS facility in the Eastern United States where most nuclear reactors are located.

2. Arguments against an MRS

Some utilities say that financing the cost of an MRS facility from the Nuclear Waste Fund would create financial inequities in the nuclear waste system because a utility's share of the cost would be proportionate to the amount of electricity it generated from nuclear reactors rather than proportionate to the extent to which it used an MRS facility. Therefore, utilities which need additional storage would derive substantially more benefit from an MRS facility than would utilities that do not need the storage.[20] Utilities that have planned for life-of-plant storage claim that it is unfair for them to have to pay both for on-site storage and for an MRS. Some oppose the MRS because they contend that the utilities can provide less expensive storage on-site than could be provided at an MRS. Therefore, the overall system costs would be greater with an MRS.

Others oppose the MRS if a plan for a western repository location and an eastern MRS site prevented western utilities from using the MRS. This "western strategy" would require the utilities to continue storing spent fuel on-site until the repository is available, at which time they would then ship the spent fuel directly to the repository. In this case, western utility ratepayers would pay proportionately the same share to build an MRS facility as ratepayers of nuclear utilities in other sections of the country. Western ratepayers, however, would not benefit directly from the facility.[21]

E. Policy Considerations

The objectives of U.S. nuclear waste policy are important considerations in evaluating the need for an MRS facility.

1. Arguments for an MRS

DOE and most utilities favor building an MRS to allow the Federal government to begin accepting utilities' spent fuel at the earliest possible time. Early acceptance of the waste, utilities argue, will allow DOE to meet its contractual obligation to begin accepting spent fuel by January 1, 1998.[22] The Nuclear Waste Policy Act of 1982 authorized the Secretary of Energy to enter into contracts with nuclear utilities for acceptance of title, subsequent transportation, and ultimate disposal of spent fuel beginning not later than January 31, 1998. DOE is to provide these services in exchange for utilities' paying fees into the Nuclear Waste Fund. Since utilities must pay into the Nuclear Waste Fund whether an MRS is built or not, utilities have strong economic reasons to insist that DOE fulfill what they claim are its contractual obligations. In addition, utility representatives express concern that nuclear power opponents would oppose on-site storage expansion.[23] These utilities believe DOE's early acceptance of spent fuel is of the utmost importance if they are to keep operating their plants.

DOE and other MRS proponents conclude that an MRS facility will positively affect the repository program by providing valuable experience in siting, licensing, and operating a large-scale waste management facility; by using proven technology earlier than the repository; and by generating the momentum needed for repository development and to boost public confidence in DOE.[24] The department has never participated in a Nuclear Regulatory Commission (NRC) licensing proceeding for any waste management facility. If an MRS facility could be licensed before a repository, DOE believes that the repository program would benefit from the MRS licensing experience.

DOE and some utility representatives also state that an MRS facility would add substantially to the waste management system's reliability and flexibility.[25] They assert that an MRS facility will provide the infrastructure needed to face an uncertain future and to respond to unforeseen emergencies.[26] Without an MRS, DOE stresses, the Nation's ability to provide for the continuous, orderly transfer of spent fuel from reactors will depend totally on achieving uninterrupted operation at a first-of-a-kind geologic repository.[27] Proponents assert an MRS would insulate reactors from slippages in the repository schedule and provide buffer capacity if disruptions occur in repository operations.

DOE asserts that an MRS facility would provide flexibility in making decisions about waste aging and the preferred location of waste packaging functions. For example, if DOE decides that aging spent fuel before emplacing it in the repository is advantageous, an MRS, DOE believes, will allow that policy to be carried out without additionally burdening utilities. DOE suggests packaging functions could be added at an MRS to minimize the repository's surface operations, thus simplifying the licensing of the repository.

Utility industry advocates of an MRS argue that timeliness in siting and constructing the facility is critical, since an MRS facility's usefulness would be diminished if it were made operational on the same schedule as a permanent repository. Advocates recommend removing or changing the linkages between the MRS facility and the permanent repository.[28] According to DOE, the advantages of having an MRS facility will be reduced significantly under current statutory provisions that link the MRS to the repository schedule.[29] In the department's opinion, achieving full benefits depends on early licensing and operation of an MRS, which can only be achieved by siting the MRS through the Nuclear Waste Negotiator with a Congressionally approved agreement that does not link an MRS's schedule to the repository schedule.[30] However, DOE stresses that the MRS will offer significant advantages even if the linkages are not revised.[31]

2. Arguments against an MRS

The most frequently heard argument against an MRS is that if an MRS is constructed, it will become a de facto repository. Opponents of an MRS assert that utility pressure on the Federal government to accept the waste will decline significantly once waste is moved to an MRS facility. Although current MRS capacity limits ensure the majority of the spent fuel will remain at the reactors, critics fear these capacity limits could be easily lifted once the facility is built and operating. Critics are concerned that the national interest in permanent disposal will erode once an interim storage facility is available to store the spent fuel safely for the foreseeable future. These opponents of an MRS believe strongly in the NWPAA linkages between an MRS facility and the repository schedule because the linkages ensure that the focus will remain on deep geologic disposal. Some opponents want the linkages strengthened.[32]

Opponents assert that an MRS will divert critical resources from the repository program. Many state that they have little confidence in DOE's ability to manage two programs successfully and simultaneously. These critics are concerned that an MRS will decrease the likelihood that geologic disposal will be developed in a timely manner.

Opponents also question system reliability and flexibility improvements. Many see an MRS as a potential bottleneck. Should a problem occur at the MRS facility, the flow of spent fuel to the repository could stop. They also claim reliability and flexibility cannot be guaranteed because siting an MRS facility will be a difficult task.[33] Many opponents regard prolonged at-reactor storage as the most flexible and reliable alternative because at-reactor storage can be added safely and incrementally in a timely manner,[34] while preventing system bottlenecks and avoiding significant siting and development uncertainties.[35]

Some believe that an MRS is not needed because the Federal government is not obligated to begin accepting commercial spent fuel in 1998.[36] In general, these opponents assert, nuclear waste management schedules established by law have not been met.

Section Three: Key Questions

Section Two recapitulated the main arguments presented to the Commission in the five study categories. This section lists the key questions to be addressed in Chapters Four through Eight.

1. Are the effects on health, safety, and the environment significantly different if some spent fuel is stored at an MRS facility instead of all being stored at reactors?
2. Are the transportation risks associated with using different routes and different modes of transport significantly different if spent fuel is stored at an MRS facility instead of at reactors?
3. What are the economic costs and benefits associated with storing spent fuel at an MRS facility as compared to at-reactor storage, and does a comparison of the costs and benefits make one option more desirable than another?
4. Are there economic and social equity issues that should be taken into consideration in determining the need for an MRS facility? If so, what are the equity issues and do they favor choosing an MRS facility over at-reactor storage?
5. Which policy issues should be taken into consideration in evaluating the need for an MRS facility, and do they make a significant difference in the evaluation?

These questions are discussed in the following chapters.

Chapter Two Notes

1. See Appendix A for a list of people who testified before the Commission and Appendix B for a list of people who submitted written statements for the record.

2. An integral MRS facility is one which would receive and eventually ship to the repository all spent fuel requiring permanent disposal, and thus integrate the MRS into the Federal waste management system. In the integral MRS, there may be a "western strategy" in which the spent fuel from western reactors would go directly to the repository.

3. Hamilton, William, Manager, Nuclear Waste Department, Westinghouse Electric Corporation, Transcript of Monitored Retrievable Storage Review Commission Public Hearings **(Hereafter cited as Hearings Transcript)**, December 1, 1988, p. 41; Smith, Ben L., Executive Administrative Assistant III, Tennessee State Planning Office, Hearings Transcript, December 1, 1988, p. 60; Mazur, Donald W., Managing Director, Washington Public Power System, Hearings Transcript, January 9, 1989, pp. 71–74; Anderson, Robert, Executive Director of Engineering, Chem-Nuclear Systems, Inc., Hearings Transcript, January 18, 1989, pp. 483–484; Parker, Mike, U.S. House of Representatives, 4th District, Mississippi, Hearings Transcript, January 18, 1989, p. 451; Keyserling, Harriet, State Representative, South Carolina Nuclear Waste Consultation Committee, Hearings Transcript, January 17, 1989, p. 234.

4. Johnsrud, Judith, Ph.D., Director, Environmental Coalition on Nuclear Power, and Research Director, Food and Water, Inc., Hearings Transcript, December 1, 1988, p. 145; Ferguson, Richard, Ph.D., Regional Vice President for Southern California/Nevada, Sierra Club, Hearings Transcript, January 9, 1989, p. 161; Eichelberger, Don, Staff Person, Abalone Alliance, Hearings Transcript, January 9, 1989, pp. 337–338; Johnson, Tim, Co-Director, Campaign for a Prosperous Georgia, Hearings Transcript, January 18, 1989, pp. 392–393.

5. Schmitz, Margaret, Pastor, Maybeury-Elkhorn United Methodist Charge, Hearings Transcript, December 2, 1988, pp. 307–308; Colonna, Andy, Private Citizen, Hearings Transcript, January 9, 1989, p. 332; Gorenflo, Louise, Rural Cumberland Resources, Hearings Transcript, January 17, 1989, pp. 284–286; Drey, Laura, News Editor, Coalition for Alternatives to Shearon Harris, Hearings Transcript, February 16, 1989, pp. 175–176.

6. Childress, Paul, Babcock and Wilcox, Nuclear Power Division, Project Manager, and American Society of Mechanical Engineers, High-level Radioactive Waste Committee, Hearings Transcript, December 2, 1988, pp. 360–361; Stephens, J.D., President, Oil, Chemical and Atomic Workers International Union 3-288, Hearings Transcript, January 18, 1989, pp. 340–342; Shiffer, James D., Vice President of Nuclear Power Generation, Pacific Gas and Electric Company, Prepared Remarks, January 9, 1989, pp. 6–7.

7. Childress, Hearings Transcript, December 2, 1988, pp. 360–361, 363; Behnke, Wallace, Vice Chairman, Commonwealth Edison Company, Hearings Transcript, January 9, 1989, pp. 22–23; McMeekin, T.C., Vice President, Design Engineering, Duke Power Company, Hearings Transcript, January 17, 1989, p. 131.

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27. Isaacs, Briefing Transcript, May 25, 1989, p. 25.

28. Hamilton, Hearings Transcript, December 1, 1988, p. 39; Mazur, Hearings Transcript, January 9, 1989, pp. 80–81.

29. Isaacs, Briefing Transcript, May 25, 1989, pp. 14–15.

30. The NWPAA provides for the creation of an Office of the Nuclear Waste Negotiator to "attempt to find a State or Indian tribe willing to host a repository or monitored retrievable storage facility at a technically qualified site on reasonable terms" and to "negotiate with any State or Indian tribe which expresses an interest in hosting a repository or monitored retrievable storage facility." 42 U.S.C. § 10242(b)(2). If a negotiator finds a willing "volunteer" state to host a repository or MRS, the proposed agreement must be submitted to Congress to be enacted into law. 42 U.S.C. § 10243(d)(3)(A).

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Chapter Three
Analytical Methodology

Chapter One defined the problem: the Commission is to compare the alternatives of having and not having an MRS in the national spent fuel management system. Chapter Two defined the issues to be considered when comparing the alternatives. Chapter Three explains the analytical methods the Commission used to compare the alternatives quantitatively.

To define the MRS and No-MRS alternatives, the Commission had to select among hundreds of variables, such as where storage, rod consolidation, and waste packaging would be performed; schedules for MRS and repository development; spent fuel discharge projections; cost assumptions; transportation schemes and modes; MRS and repository locations; and cask types and capacities. The Commission selected the most significant variables and used them to define the alternatives on which it focused its evaluation.

The Commission defined two basic categories of spent fuel management systems (MRS and No-MRS alternatives), identified the variables most likely to affect its decision on the need for an MRS, and developed analytical models to enable it to compare quantifiable aspects of the alternatives. Section One of this chapter describes, in general terms, the two basic interim spent fuel management alternatives which the Commission evaluated. Section Two explains the computer models developed to examine the quantifiable costs and risks. Section Three lists the principal assumptions used to define the base cases that were evaluated for the alternatives. That is, this section discusses the important variables in choosing among alternatives and explains what values the Commission assigned to those variables to analyze the base cases. Section Four discusses the variations on the base cases that were evaluated.

Section One: No-MRS and MRS Alternatives

The Commission evaluated approaches to interim spent fuel storage that fell into two basic categories: 1) **the No-MRS alternatives,** in which all spent fuel continues to be stored at the reactor sites until a repository becomes available and 2) **the MRS alternatives,** in which some spent fuel is stored at a central Federally-owned facility until a repository becomes available. (See Figure 3.1.)

To analyze the alternatives, the Commission postulated three start-up dates for the repository: 2003, 2013, and 2023. The 2003 date reflects DOE's current schedule for repository availability.[1] The Commission chose to analyze the cases using the other dates to examine whether and how schedule delays might affect the Commission's conclusions.

A. The No-MRS Alternatives

In the No-MRS alternatives analyzed by the Commission, all fuel would be stored at the reactor sites until DOE was ready to accept the waste and ship it to the repository for disposal. The analysis assumed utilities would select from a number of currently available options to provide interim storage. These include: reracking, which increases pool storage capacity by refitting spent fuel pools with racks that hold more fuel assemblies; and dry storage, which stores spent fuel in metal or concrete casks, or in concrete bunkers. The analysis also considered whether additional options, such as dual-purpose casks (single casks that can be used for both storage and transportation), rod consolidation (decreasing pool storage requirements by taking apart intact spent fuel assemblies and combining them to reduce their volume), and transshipment (shipping fuel from one reactor site to another), would be available and, if so, how their use would affect the choice between the No-MRS and MRS options.

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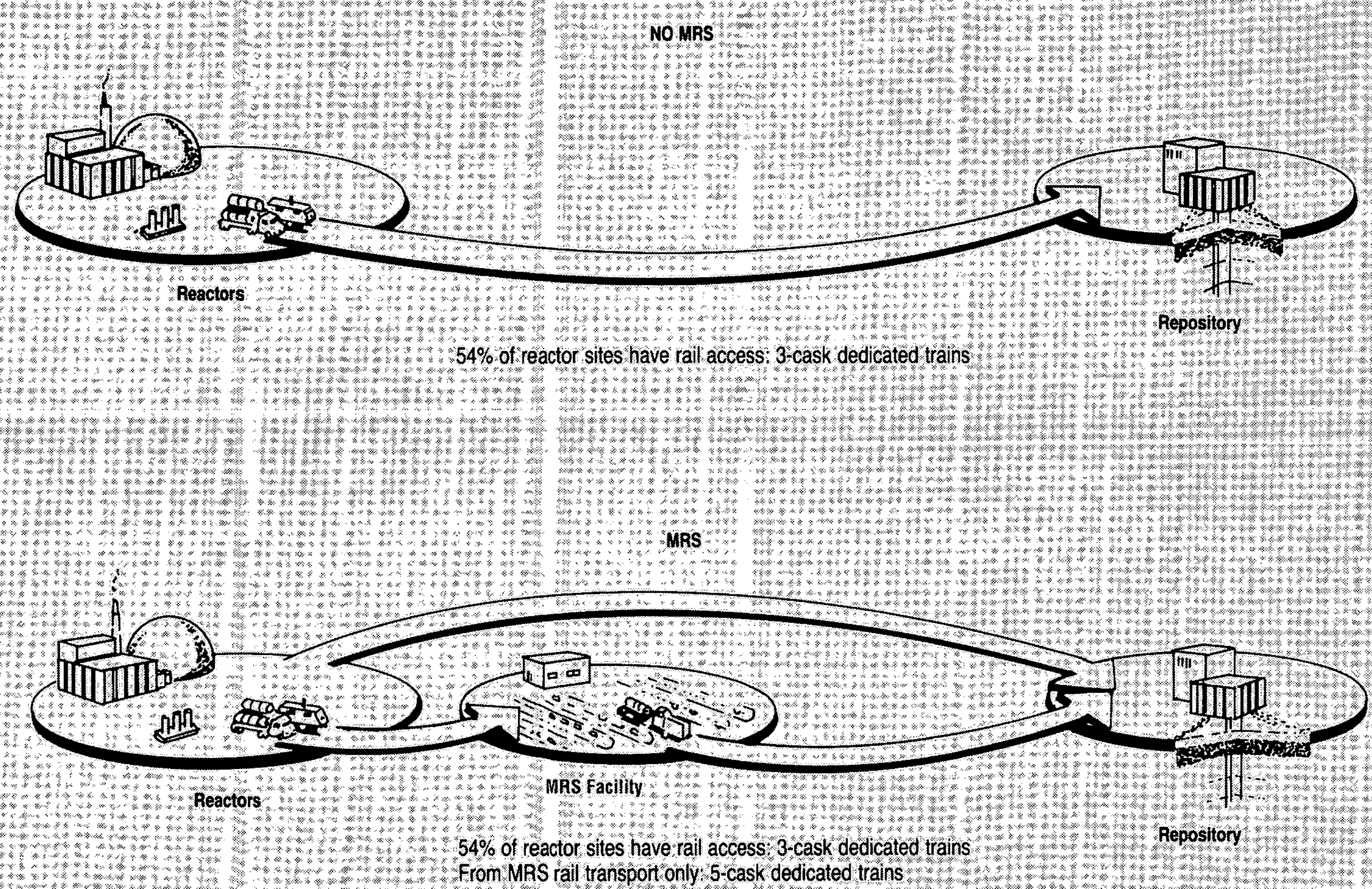
Figure 3.1—Interim Storage Concepts



B. The MRS Alternatives

In the MRS alternatives analyzed by the Commission, spent fuel would be stored at the reactors until an MRS became available. Some spent fuel from some reactors would be transported and stored at an MRS until a repository were available for permanent disposal. The MRS would continue to operate until all the spent fuel had been emplaced in the repository.

The MRS facility was analyzed with the schedule and capacity linkages defined in the Nuclear Waste Policy Amendments Act of 1987,[2] with alternative linkages, and without linkages. With the MRS capacity limited under current law to 15,000 metric tons uranium (MTU), most spent fuel would be stored at the reactor sites at any given time. The MRS, then, would supplement at-reactor storage.

Under the current statutory schedule linkages, construction of the MRS cannot begin until the NRC has issued a license for the construction of the repository, and construction of the MRS is "prohibited during such time as the repository license is revoked by the Commission [NRC] or construction of the repository ceases."[3] DOE estimates that it will take at least 30 months to build a storage-only MRS[4] and at least five years to construct a repository.[5] If repository construction authorization were received in 1998, for example, DOE believes that, with the current linkages, an MRS could begin accepting waste in the year 2000, and a repository could begin operation in 2003.[6] Therefore, a linked MRS would be available about three years before the repository, assuming construction proceeds according to the projected schedules.

Section Two: The Models

Most experts who expressed opinions to the Commission seemed to agree that the effects on public health and safety would be small and within regulatory limits regardless of whether an MRS were included in the waste management system. However, members of the public expressed concerns about the safety of various storage alternatives and greater concerns about the safety of transporting spent fuel. The Commission decided it needed to develop its own estimates of the costs and effects of the various spent fuel management alternatives as well as a method for comparing its estimates to those of DOE and Tennessee.

To compare system-wide estimates of risks and costs, the Commission developed computer models that describe the flow of spent fuel through the spent fuel management system. These models are described briefly below; Appendix G gives a more detailed description.

A. The System Model: MARC

The model used to evaluate the risks of different system configurations was MARC: **M**RS Review Commission's **A**nalysis of System **R**isk and **C**ost. It is a network model adapted from a DOE model.[7] (See Figure 3.2.)

The DOE model from which MARC was adapted (TRICAM) calculated only transportation costs and risks. TRICAM was used by DOE only in the simulation mode, with "oldest fuel first" (OFF) always specified as the pick-up rule to be followed. However, because the Commission's systems analysis encompasses more than transportation, the model had to be modified to calculate the risks of storage and of performing other functions, such as handling spent fuel, at the various facilities within the waste management system. The model also includes estimates of the costs of the various waste management functions, many of which were adapted from the cost accounts developed in the economic cost model described below.

MARC shows how the spent fuel would be handled and transported through the waste management system from the time it is discharged from the reactors to the time it is placed in a repository. MARC calculates the costs and risks for each step in the flow. MARC is designed to operate in the "optimization mode," to figure out which combination of transporting and storing the spent fuel will incur the least cost or least risk. The resulting "pick-up rule" reflects the least cost or risk sequence and modes by which spent fuel is to be picked up from the reactors by DOE and shipped to an MRS or repository.

MARC can be programmed to optimize either cost or radiological risk or some combination thereof. Most of the cases were run in the cost optimization mode (to minimize costs) because this mode was likely to produce higher (or more "conservative") estimates of system risks. Some cases were run in the risk optimization mode (to minimize risks). The differences in radiological risk from the risk optimization and the cost optimization runs were small and these differences will be discussed in Chapter Four.

Although MARC was designed to be run in the optimization mode, it can be run in the simulation mode, in which a pick-up rule (such as oldest fuel first) is specified in advance and the model simulates the combination of

Figure 3.2—Illustration of a Network Model
A City-wide Courier Service

A city-wide courier service provides a good example of how a network model works. The company computer receives information about which packages of what weights are to be picked up from various locations and taken to other locations, and then figures out a schedule of pick-up from and delivery to customers within a prespecified time, in a way that minimizes the company's costs.

For the computer program, certain *assumptions* must be made, such as how long it would take a courier to go a certain number of miles and what routes were better than others. The computer is instructed to choose the optimal (best possible) delivery schedule and carriers to achieve the company objectives about delivery speed and cost; that is, it may be told to *"optimize"* for those two objectives. The result is the *"pick-up rules"* to accomplish this, such as which packages are to be picked up, when, and by which carrier. When the computer gets information about what is to be picked up where, what the destinations are, and who is working, it models a schedule for each carrier, figuring out the most efficient combinations.

For certain purposes, the computer can be told to *"simulate"* rather than "optimize." That is, it can be told to follow a particular rule, or that a particular package is to be picked up first, even if doing so costs the company more money. It then models the best possible schedules and carriers, given that condition.

Obviously, some judgments have been made in the basic assumptions, such as the delivery van's size. It might be useful for the company to see what effect changing this one assumption would have on meeting the schedule and on costs. The computer's user could come up with a sample case and analyze it using the usual assumptions; then the user could change the data on van size and see how that changes the costs. This is called "sensitivity analysis".

storing, handling, and transporting spent fuel that would result; it also estimates the system-wide costs and risks of this particular combination. However, MARC is very difficult to use in the simulation mode, because the user must describe the pick-up rule in advance, which requires a detailed schedule of the annual acceptance of spent fuel on a reactor-by-reactor basis. MARC was run in the simulation mode and the results were similar to those of DOE's TRICAM simulation. However, because of the difficulties in pre-specifying a pick-up rule, the Commission did not rely on MARC simulation runs to perform its analysis of the MRS and No-MRS alternatives.

MARC receives information from several data bases, using them to describe how spent fuel would move through the system and to calculate risks and costs. The principal data bases provide facility-specific data, such as reactor spent fuel discharge projections, reactor rail accessibility, and repository capacity and acceptance schedules. Other data bases provide network data, such as routes, population density along the routes, unit risk data, and unit cost data. Unit cost data used in MARC come from the cost model data base described below. The transportation radiological unit risk factors used in MARC are from a modified version of RADTRAN III supplied by DOE. The radiological unit risk factors for activities at fixed facilities are taken from Commission-sponsored assessments.[8] Appendix G and the MARC user manual describe the model and the associated data bases.[9]

B. The Cost Model: WACUM

The Nuclear **WA**ste **C**ost Data Base and Sim**U**lation **M**odel (WACUM) is a simulation model, with an accompanying data base, for computing costs.[10] The model estimates costs for the two basic alternatives and variations on them. WACUM was designed to analyze the uncertainties associated with the costs of the various elements of the spent fuel management system, including constructing and operating an MRS, and to provide cost estimates to be used in MARC.

The basic cost data used in the model are subject to a wide range of uncertainty. In many cases, the estimates involve predicting the costs of yet-to-be developed equipment and facilities over a 40- or 50-year time period, with a still-evolving regulatory regime, and uncertain institutional framework.

The accompanying data base[11] has two parts: a historical data base, which summarizes the past cost estimates, and a probabilistic data base, which was used in the calculation. The probabilistic data base was derived by a panel of experts who reviewed the historical data base to estimate future costs in a subjective but structured manner. WACUM is explained more fully in Chapter Six, where its results are discussed, and in Appendix G.

C. Uses of Models

The models are used to enable comparisons among the alternatives, so the Commission can make more informed recommendations. Models are tools to assist judgments, and their usefulness depends on some degree of skepticism about the certainty of data and assumptions.

There are uncertainties associated with radiological risk predictions, especially for the low exposure levels associated with projected spent fuel management operations, and potential accidents associated with these operations. Health effects (primarily risk of cancer) from exposures to low radiation doses would not be expected to appear for 20 to 30 years, and are predicted using conservative estimates based on observed health effects resulting from exposures to much higher radiation doses at much higher rates. Using a computer model does not reduce these uncertainties since the uncertainty in computer output can be no less than that in the input data and assumptions.

However, using a computer which systematically models the flow of materials through the spent fuel management system, and the activities associated with this flow, provides a means for conducting a systematic and consistent comparison of risks among spent fuel management alternatives. Therefore, although the absolute levels of radiation doses for a given case cannot be determined accurately, the Commission was able to detect trends and to rank order alternatives in the instances when the trends were considered significant.

Because of the difficulty of using MARC in the simulation mode, and because the model was not available until much later than the WACUM model which was developed specifically to do cost assessments, the Commission used WACUM for all cost assessments. MARC produces both cost and risk estimates but was used in the study only to assess and compare risks. In the MARC and WACUM runs the cost relationships among the cases analyzed are the same. The Commission also decided to run sensitivity analyses to test the effects that changing certain assumptions would have on the results. These sensitivity analyses are described in Section Four.

Section Three: Assumptions of MRS and No-MRS Strategies

To further define the base cases to be analyzed by MARC, the Commission made certain assumptions about the spent fuel management system. (See Figure 3.3.) Where possible, the same assumptions were made about both the MRS and No-MRS alternatives to facilitate comparing costs and benefits. The assumptions described below were made for the base cases.

A. Maximum Exposures

Assumptions: *During each function performed to handle and transport spent fuel, workers and members of the general public are expected to receive as much as, but not more than, the maximum radiological doses specified in NRC and EPA regulations.*

The principal safety and environmental regulations applicable to the waste management system are those of the Nuclear Regulatory Commission and the Environmental Protection Agency.[12] The models assume these regulations will be strictly enforced and, therefore, that the maximum expected radiation doses for normal and accident conditions should be within these regulatory limits. In practice, the expected doses should be less than the regulatory limits because facilities and equipment are designed to ensure a margin of safety in the design, and doses are required to be kept "as low as reasonably achievable" (ALARA).[13]

B. Spent Fuel Generation

Assumptions: *There will be no new orders for nuclear power plants; base cases include only spent fuel from plants operating or being constructed as of December 1987; no substantial change will occur in burnup rates, post-1988 projected burnup rates of 36,600 megawatt-days per metric ton uranium (MWd/MTU) for boiling water reactors (BWRs), and 42,000 MWd/MTU for pressurized water reactors (PWRs);[14] and each plant will have a 40-year operating life.*

DOE's 1986 spent fuel storage projections were based on an optimistic high-generation projection of nuclear power growth in the United States instead of the no new orders cases. The National Association of Regulatory Utility Commissioners (NARUC), the State of Tennessee, and the

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Figure 3.3—No-MRS and MRS Modeling Assumptions

- Maximum radiation doses are to be within regulatory limits
- Spent fuel generation: DOE 1987 No New Orders projections[a]
- Single tier reracking to the maximum extent feasible
- Full core reserve always maintained
- No transshipment assumed
- Out-of-pool additional storage provided by existing dry storage technologies
- No at-reactor rod consolidation
- Any MRS will be storage-only MRS
- Any MRS will use dry storage
- Any MRS will be located in the Eastern United States
- Risks of performing a function such as storage, rod consolidation or encapsulation are the same whether the function is performed at an MRS or the repository
- All spent fuel generated will be disposed of in a single repository located at Yucca Mountain, Nevada
- Repository will have a minimum operating life of 25 years and a maximum of 45 years
- Transportation modes: only rail and highway
- From-reactor rail/highway mode split: *per DOE transportation system study* (only 54% of reactors have rail access)

[a] Department of Energy, "Spent Fuel Storage Requirements 1988," DOE/RL-88-34, October 1988.

General Accounting Office (GAO) challenged these projections.

DOE's most recent projections, however, are based on no new orders for nuclear power plants, and are used in this study (1987 No New Orders Case.) The estimates are generally consistent with the NARUC and Tennessee projections, and they respond to GAO's objections.

C. Storage and Other Functions at Reactors

1. Reracking

Assumption: *Every nuclear utility will rerack its spent fuel pools (single-tier reracking only) to the maximum extent practicable before it uses other options such as rod consolidation or dry storage.*

Reracking means refitting pools with racks that hold more fuel assemblies than the initially installed racks. Reracking has been the utilities' preferred method of increasing at-reactor spent fuel storage, in part because it is the most economical way to increase storage space. The added racks handle heavier loads and store fuel assemblies in less space. Most utilities have reracked their pools at least once. While some reactors may have to use other measures to acquire additional storage capacity, about 75 percent of the reactors can provide sufficient storage using reracking until beyond the year 2000.[15]

According to recent NRC figures, there have been 130 rerackings.[16] From the original typical design of 1-1/3 reactor cores, utilities have increased storage to four to six reactor cores, in some cases even more. Future reracking will be limited; adding a second tier of racks is not consid-

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ered a practical way to expand spent fuel storage capacity.[17]

2. Full-Core Reserve

Assumption: *Every utility will maintain enough pool storage capacity so that it can unload the full core of the reactor into the spent fuel pool, if necessary. This is commonly referred to as full-core reserve.*

Although full-core reserve is not an NRC requirement most utilities view maintaining full-core reserve as essential for orderly nuclear power plant operation.

3. Transshipment

Assumption: *There will be no transshipment of spent fuel between reactor sites.*

Transshipment means shipping spent fuel from one reactor to another to alleviate storage problems. Carolina Power and Light Company and Duke Power Company have transshipped spent fuel within their individual utility systems. However, widespread intrautility shipments have not occurred, and there have been no interutility transshipments. Variations on this basic assumption were analyzed, assuming some intrautility transshipment (See Chapter Five for details.)

4. Dry Storage

Assumption: *Reactors unable to expand their spent fuel pool capacity will use dry storage if additional on-site storage is needed.*

Dry storage means storing spent fuel at reactor sites in metal casks, concrete casks,[18] or concrete bunkers.[19] (See Figures 3.4 and 3.5.)

A typical metal dry storage cask is made of steel or nodular cast iron. Virginia Power Company's Surry Nuclear Power Station uses a metal cask dry storage system. In bunker systems, the fuel is stored in stainless steel canisters contained in individual concrete modules. The Carolina Power and Light Company's Robinson Nuclear Project uses a small bunker system, which holds seven pressurized water reactor (PWR) assemblies per module. Duke Power Company has applied for a license for a larger bunker system, holding 24 PWR assemblies per module, at the Oconee plant.

Most utilities will probably be able to store enough spent fuel in dry storage on-site to obtain life-of-plant storage capacity, either at the reactor sites or on utility-owned land contiguous to the reactor. It has been estimated that fuel could be stored safely in dry storage for up to 100 years.[20]

5. Rod Consolidation

Assumption: *No spent fuel will be consolidated at reactors.*

Four utilities have participated in rod consolidation demonstrations. Because the technology has not yet been shown to be technically and economically advantageous, no utility has chosen to rely on rod consolidation to expand on-site storage capacity. Therefore, for the two alternatives being considered, the analysis assumes no spent fuel will be consolidated at reactors. Sensitivity analyses were run, however, assuming some rod consolidation at reactors because the technology may mature to the point where it would be a useful alternative storage option. (See also, MRS Assumptions, below.)

D. MRS Assumptions

1. Functions

Assumption: *Any MRS will only provide spent fuel storage and will not perform other functions such as rod consolidation or waste packaging.*

The Commission focused its analysis on the storage-only MRS because of DOE's current position that an MRS will be a storage-only facility at first, with the option of adding other functions later.[21] DOE now finds that savings attributable to consolidation are not substantial enough to make consolidation worthwhile.[22] However, as the system-wide parameters are further defined, the cost of the waste package container may become high enough for rod consolidation to be reconsidered. Therefore, the Commission considered how adding other functions later, such as rod consolidation, would affect the choice between the No-MRS and MRS options.

2. Storage Technology

Assumption: *Any MRS facility will use dry storage rather than pool storage.*

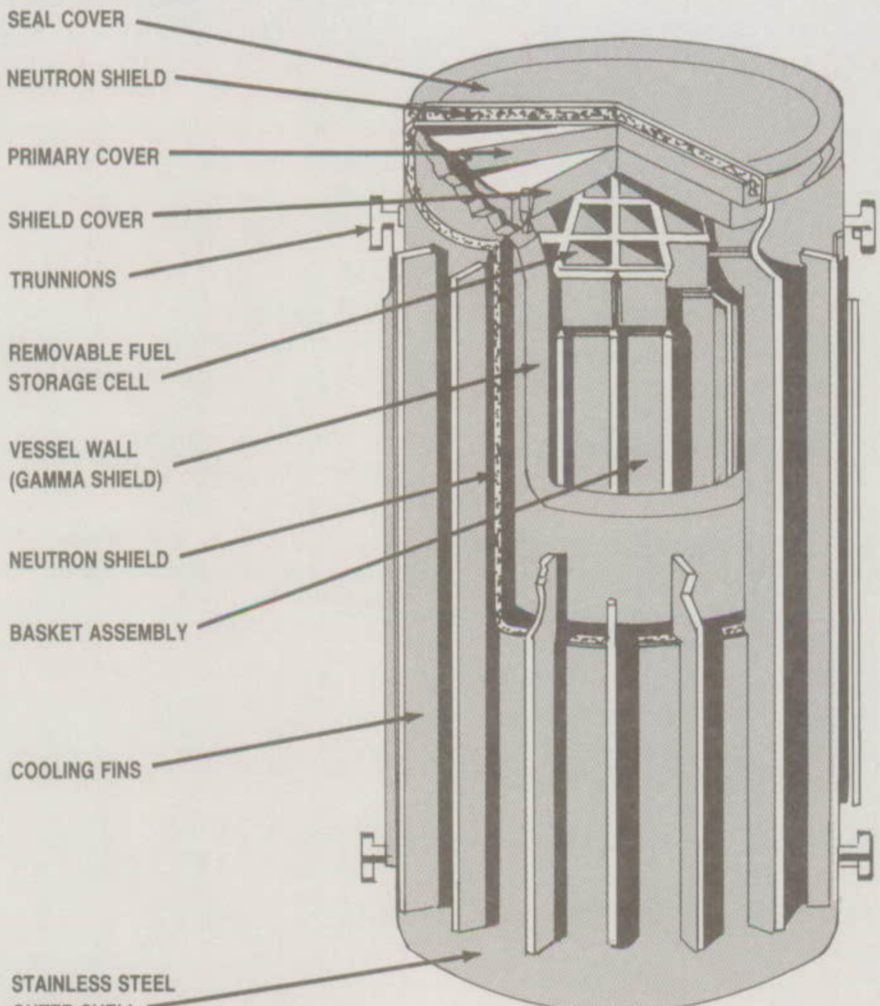
Dry storage is DOE's technology of choice for the MRS. DOE prefers dry storage to wet storage because dry storage is a passive technology, requiring less monitoring and control than wet storage does. In addition, dry storage is partially modular, requiring a smaller initial investment to build.

3. Risks

Assumption: *Risks of performing a function such as storage, rod consolidation, or encapsulation are the same whether the function is performed at an MRS or a repository.*

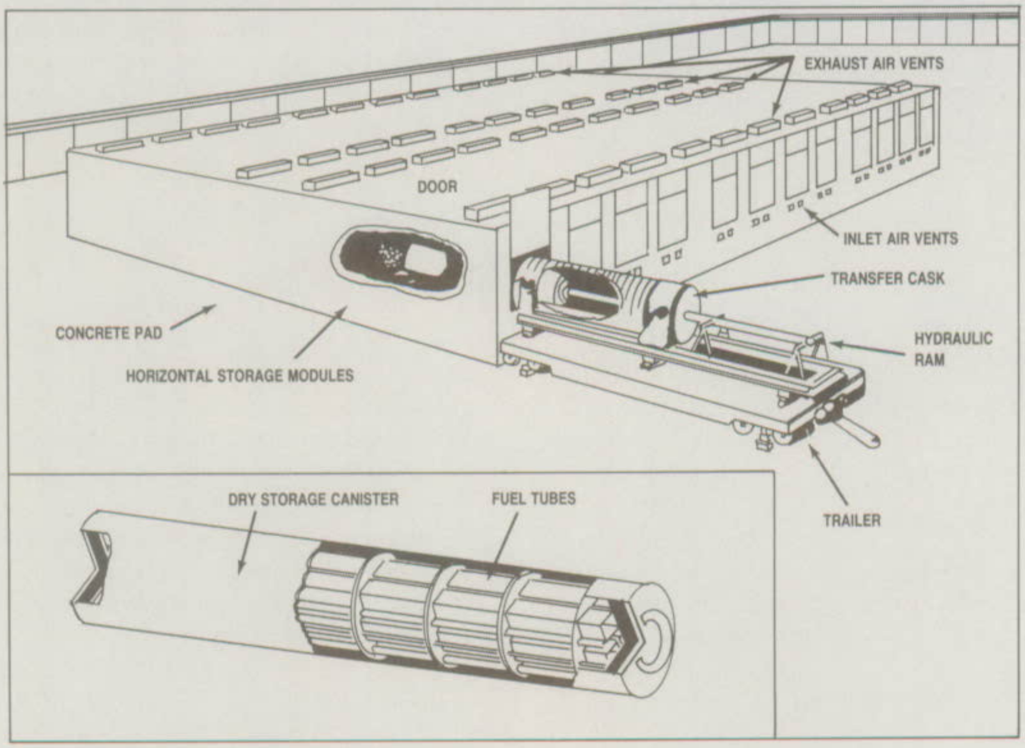
The equipment, facility design, and operation for these functions is expected to be the same regardless of where the function is carried out.

Figure 3.4—An Example of a Dry Storage Cask



SOURCE: ELECTRIC POWER RESEARCH INSTITUTE

Figure 3.5—Generic Horizontal Modular Storage System (NUHOMS)



SOURCE: DEPARTMENT OF ENERGY

4. Location

Assumption: *Any MRS will be located in the Eastern United States.*

For its transportation and cost analyses, this study postulates hypothetical locations for an MRS. See Appendix G for an explanation.

E. Repository Schedule and Location

Assumptions: *All of the spent fuel generated will be disposed of in a single repository located at Yucca Mountain, Nevada. The repository will have a minimum operating life, for accepting and emplacing spent fuel, of 25 years and a maximum operating life of 45 years.*

The Commission had to postulate a repository location to analyze the effect of an MRS on the waste management system, and at the moment, site characterization efforts are focused on Yucca Mountain. It may be many years before the suitability of the Yucca Mountain site is determined. If it is found to be unacceptable, the issue of how best to manage the Nation's radioactive waste will be reexamined. Although the location of the repository was not varied in the base cases, several variations were analyzed assuming delayed repository start-up to determine the effects of such delays on the need for an MRS.

Under current law, the capacity of the first repository is limited to 70,000 MTU until a second repository is in operation.[23] However, to obtain a realistic estimate of life-cycle risks, costs, and benefits associated with spent fuel management, it was necessary to model a system which handles all of the commercial spent fuel expected to be generated, about 87,000 MTU. Introducing a second repository in the system would have significantly increased model complexity and uncertainty because the model would have had to assume some location and schedule for the second repository, both very uncertain. To reduce the complexity to a manageable level, it was assumed that all of the spent fuel would go to the first repository. The Commission believes that the potential error introduced by making this assumption is less than could have been introduced if a second repository site had been postulated.

F. Transportation Modes

Assumptions: *Only railroads and highways are used to transport spent fuel. The base cases assume that only 54 percent of the reactors have rail access.*

This division into percentages is called a modal split; truck transport and rail transport are called modes.[24] DOE assumed this 54 percent/46 percent modal split in its MRS system study.[25] Barge transport was not considered because it was not seen as having a significant effect on the MRS/No-MRS decision. For trips to Yucca Mountain, whether from reactors or from a candidate MRS, barge transport could be, at most, only one segment of an intermodal shipment. It has been suggested that barges may be feeders to a railhead from those reactors with waterway access but without rail access. The model has been run using 100 percent rail transport in some cases to simulate the economic advantages of providing barge-supplemented rail access in this manner.

Section Four: Sensitivity Analyses

To see how changes in some assumptions would affect the analyses, the Commission conducted "sensitivity analyses." That is, after analyzing the base cases defined with the primary set of assumptions, the same cases were analyzed with one assumption changed at a time to see how great a difference, if any, that would make. For example, in the base case, the Commission assumed that only 54 percent of the reactors have access to rail transport. To see what difference it would make if more reactors could gain rail access, an idealized case was analyzed in which all reactors were assumed to have rail access. Such changes are called variations on the assumptions. (A list of the variations considered by the Commission is contained in Appendix H.) Variations were chosen that were realistic or else bounded the effects of the change. For example, there cannot be any transportation efficiency greater than 100 percent rail. Chapters Four through Six describe the results of these analyses.

Chapter Three Notes

1. Isaacs, Thomas H., Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE Position on the Monitored Retrievable Storage (MRS) Facility," Prepared Remarks before the Monitored Retrievable Storage Review Commission, May 25, 1989 **(Hereafter cited as Isaacs, Prepared Remarks),** p. 4; "MRS System Study Summary Report," DOE/RW-0235, June 1989, **(Hereafter cited as Task J),** p. 69.

2. 42 U.S.C. § 10168(d).

3. 42 U.S.C. § 10168(d).

4. Task J, pp. 13–16.

5. Department of Energy, "Draft 1988 Mission Plan Amendment," DOE/RW-0187, June 1988, pp. 21, 50–52.

6. Isaacs, Prepared Remarks, May 25, 1989, p. 4.

7. **TRICAM**: Transportation **RI**sk and **C**ost **A**nalysis **M**odel. See, Office of Transportation Systems and Planning, Battelle Nuclear Systems Group, "MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility," BMI/OTSP- 07, May 1989 **(Hereafter cited as Task F),** pp. 14–15, and 18.

8. Letter Report from ICF Technology Inc., September 14, 1989, by Steve Baker, 601 Williams Boulevard, Fourth Floor, Richland, Washington 99352-3258; Golder Associates, Inc., "Final Report of Safety and Environmental Impacts for Alternative Spent Fuel Management Options," July 1989.

Radiological unit risk factors are usually expressed as person-rem/shipment-kilometer for transportation and person-rem/MTU of fuel handled or person-rem/activity for activities at fixed facilities.

9. ICF Technology, Inc., "MARC User Manual and Model Documentation," July 1989.

10. Golder Associates, Inc., "WACUM: Nuclear Waste Cost Database And Simulation Model User's Guide Version 1.13: Report to the Monitored Retrievable Storage Review Commission," 893-1032.210, June 20, 1989.

11. Golder Associates, Inc., "Interim Spent Fuel Management Cost Data Base: Report to the Monitored Retrievable Storage Review Commission," 893-1032.120, June 1989.

12. **Radiation Safety and Environmental Regulations**

EPA

- 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations (the language of Part 190 is incorporated into 10 CFR Part 72)
- 40 CFR Part 191, Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes
- 40 CFR Part 141, National Interim Primary Drinking Water Regulations (40 CFR 141.15 and 141.16 specify radioactivity standards)

NRC

- 10 CFR Part 20, Standards for Protection Against Radiation
- 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities
- 10 CFR Part 51, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions
- 10 CFR Part 71, Packaging and Transportation of Radioactive Material
- 10 CFR Part 72, Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)
- 10 CFR Part 73, Physical Protection of Plants and Materials
- 10 CFR Part 74, Material Control and Accounting Of Special Nuclear Material

A more complete list of potentially applicable regulations and guidance is shown in the Department of Energy, "Monitored Retrievable Storage Submission to Congress," DOE/RW-0035/1, Vol. II, February 1986, Appendix I.

13. 10 CFR 20.1(c).

14. "Burnup" is a measure of consumption of fissile content of reactor fuel, expressed as either the percentage of fuel atoms that have undergone fission, or the amount of energy released per unit mass of nuclear fuel in the reactor. Units normally used for the latter are megawatt-days per ton of uranium or heavy metal.

The terms "metric tons of uranium" (MTU), "metric tons of heavy metal" (MTHM) and "metric tons of initial heavy metal" (MTIHM) are all used in the literature. In its spent fuel projections, DOE expresses burnup in terms of megawatt days per metric ton of initial heavy metal (MWd/MTIHM). Although these terms are not precisely equivalent, the error introduced by using these terms interchangeably is between 2-3 percent and well within the uncertainties associated with estimating costs and risks associated with management of spent fuel. (See, for example, Department of Energy, Energy Information Administration, "World Nuclear Fuel Cycle Requirements 1988," DOE/EIA - 0436(88), 1988, Table B4, p. 63.) Therefore, to make the report more readable, burnup is expressed in terms of megawatt-days per metric ton of heavy metal.

15. Ebasco, "Spent Fuel Storage Need and At-Reactor Capability Study," June 1989 **(Hereafter cited as Ebasco, Need Study),** Table 3-3.

16. Ebasco, Need Study, p. 3–1.

17. Ebasco, Need Study, p. 3–5.

18. Two types of concrete casks have been designed. Both are made of heavily reinforced concrete with an inner metal liner. The unventilated type will hold 9 PWR or 25 BWR fuel elements, and weigh about 90 tons when loaded. The ventilated type will hold 17 PWR or 50 BWR elements, and weigh about 125 tons when loaded. The NRC is evaluating a Topical Report for a ventilated cask but has not yet made a decision on certification.

19. Department of Energy, "Final Version Dry Cask Storage Study," February 1989, Chapter 4.

20. On August 31, 1984, the NRC issued a final decision on what has come to be known as its "Waste Confidence Proceeding." In that proceeding, the Commission's Fourth Finding was that the Commission had "reasonable assurance that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the expiration of that reactor's operating license at that reactor's spent fuel storage basin, or at either on-site or off-site independent spent fuel storage installations." 49 FR 34658.

In its recently published proposed Waste Confidence Decision Review, 54 FR 39767 (September 28, 1989), the Commission proposed that this finding be revised to read: "The Commission finds reasonable assurance that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the *licensed life for operation (which may include the term of a revised license) of that reactor* at its spent fuel storage basin, or at either on-site or off-site independent spent fuel storage installations." [Revised portion in italics]

In discussing the basis for revising this finding the NRC stated, "In making the original Fourth Finding, the Commission did not determine that for technical or regulatory reasons, storage would have to be limited to 70 years. This is apparent from the Commission's use of the words '. . . for *at least* 30 years beyond the expiration of that reactor's operating license . . .' [emphasis added]. Similarly, in using the words 'at least' in its proposed revised Finding Four, the Commission is not suggesting 30 years beyond the licensed life for operation (which may include the term of a revised license) represents any technical limitation for safe and environmentally benign storage. Degradation rates of spent fuel in storage, for example, are slow enough that it is hard to distinguish by degradation alone between spent fuel in storage for less than a decade and spent fuel stored for several decades . . . The Commission does not see any significant safety or environmental problems associated with storage for at least 30 years after the licensed life for operation of any reactor, even if this effectively means storage for at least 100 years, in the case of a reactor with a 70-year license for operation. . .Thus, supported by the consistency of NRC experience with that of others, the Commission has concluded that spent fuel can be stored safely and without significant environmental impact, in either wet storage or in wet storage followed by dry storage, for at least 100 years."

Although this is a proposed finding at this time, it is the latest statement resulting from a detailed technical review of this issue.

21. Isaacs, Prepared Remarks, May 25, 1989, pp. 1, and 5–6.

22. Isaacs, Prepared Remarks, May 25, 1989, pp. 6–7; Task J, pp. 38–39, 70.

23. 42 U.S.C. § 10134(d). The 70,000 MTU in the statute can include both spent fuel and defense HLW. The DOE studies contemplate that the first repository will hold approximately 63,000 MTU of commercial spent fuel and approximately 7,000 MTU of defense waste.

24. Mode split usually refers to tonnage actually carried by truck or rail rather than sites served, as it is used here.

25. Task F, p. 15.

Chapter Four
Health, Safety, and Environmental Effects

Public health and safety, and environmental protection are serious concerns of the American people and were of highest priority to the MRS Review Commission during its study. This chapter compares the health, safety, and environmental effects of two alternative approaches to spent fuel management: having and not having an MRS facility. Section One covers radiological and non-radiological effects on health and safety. Section Two discusses special issues pertaining to health and safety that were raised during this study. Section Three considers potential environmental and socioeconomic effects. Section Four sets forth the Commission's findings regarding these effects. This chapter also summarizes the estimated radiological risks of transporting spent fuel, but Chapter Five covers transportation safety more fully.

Section One: General Effects on Health and Safety

A. Radiological Effects

Radiation doses to workers and the public can result from spent fuel management operations at the reactor, the repository, or the MRS, and from transporting spent fuel from one facility to another.

Radiation exposure for each of the base cases (No-MRS, linked MRS, and unlinked MRS) was estimated for each of three different repository start dates (2003, 2013, and 2023). Tables 4.1 and 4.2 summarize the results. Dose estimates are reported in terms of cumulative doses to workers and the public expected over the entire 40-year life of the spent fuel management program, from the time the fuel is removed from the reactor core until all the spent fuel has been buried in a geologic repository. These doses are referred to as "life-cycle" doses and are expressed in person-rem.[1]

1. General Findings About Dose Magnitude

The study found radiation dose estimates for the workers and the public to be very low for all of the cases and all of the repository start dates examined. (See Table 4.3.)

In terms of latent cancer fatalities, calculations of occupational fatalities range from 6.8 to 10.4, a difference of 3.6 fatalities, and predictions of public fatalities range from 1.4 to 3.2, a difference of 1.8 fatalities. Cancer fatality calculations assume that each 10,000 person-rem will produce four cancer fatalities.[2] These estimates are for the entire United States over the spent fuel management program's 40-year life cycle. These differences amount to about one calculated occupational cancer fatality every 11 years and one calculated public cancer fatality every 22 years, assuming a 40-year life for the spent fuel management program.

The total life-cycle public dose from the entire spent fuel management system for either the MRS or No-MRS alternatives would produce a calculated risk of about 0.04 to 0.08 cancer deaths per year, assuming a 40-year life for the system. This is illustrated in Figure 4.1.

The population within 50 miles of an MRS would receive about 0.1 person-rem per year[3] from the operations at the MRS. This would produce about 0.00004 calculated cancer deaths per year.

For comparison, the background radiation dose to the estimated population within 50 miles of an MRS would be about 300,000 person-rem per year. Background radiation doses to the population within 50 miles of an MRS are calculated to produce about 120 cancer deaths per year. Exposures to medical x-rays for the same population would result in doses of about 39,000 person-rem and are calculated to produce about 15 cancer deaths per year.[4]

2. Public Dose

"Public dose" is defined as the total dose to members of the public (as opposed to workers) during all activities

7 0 2 3 9 2 0 7 4

Table 4.1—Total Spent Fuel Management Life-cycle Public Doses (Person-rem)

	REPOSITORY START DATE		
Case	2003	2013	2023
No-MRS	8,100	8,100	8,100
Linked MRS (NWPAA)[a]	3,500[b]	3,500[c]	3,600
Unlinked MRS	3,500[b]	3,500[c]	4,000

[a]MRS begins accepting spent fuel three years before repository start date.

[b]For a 2003 repository start date, the linked and unlinked MRS cases are the same because in both cases the MRS is assumed to start in the year 2000.

[c]The numbers are the same because of rounding off.

associated with storing, handling, transporting, or disposing of spent fuel. Most of the dose to the public occurs during transport; the transportation dose accounts for over 95 percent of the total public dose in both MRS and No-MRS systems. (See Table 4.4.) It should be noted that in-transit doses to truck drivers and train crews are included in the public dose estimates from transportation; excluding these doses from the estimates would reduce public doses by as much as 75 percent.[5].

Without an MRS, public doses would be essentially the same regardless of the repository start date. (See Table 4.1.) Having an MRS in the system would reduce these doses by about 60 percent. This reduction would occur because all transportation from the MRS to the repository would be by train, thereby reducing the transportation dose.

3. Occupational Dose

"Occupational dose" is defined as the total dose to workers during all activities associated with the storing,

Table 4.2—Total Spent Fuel Management Life-cycle Occupational Public Doses (Person-rem)

	REPOSITORY START DATE		
Case	2003	2013	2023
No-MRS	16,600	26,100	31,500
Linked MRS (NWPAA)[a]	16,000[b]	22,300	31,000
Unlinked MRS	16,000[b]	17,000	18,200

[a]MRS begins accepting spent fuel three years before repository start date.

[b]For a 2003 repository start date, the linked and unlinked MRS cases are the same because in both cases the MRS is assumed to start in the year 2000.

Table 4.3—Comparison of Total Life-cycle Radiological Effects of MRS and No-MRS Systems (2013 Repository Start Date)

	OCCUPATIONAL EXPOSURE		PUBLIC EXPOSURE	
	Person-Rem	Calculated Cancer Fatalities	Person-Rem	Calculated Cancer Fatalities
No-MRS	26,100	10.4	8100	3.2
Linked MRS (NWPAA)[a]	22,300	8.9	3500	1.4
Unlinked MRS[b]	17,000	6.8	3500	1.4

[a]Linked MRS to begin operations in 2010.
[b]Unlinked MRS to begin operations in 2000.

handling, transporting, and disposing of spent fuel.

Occupational doses would increase as the repository start date was delayed. They would nearly double for the No-MRS and linked MRS cases if the repository start date was delayed from 2003 to 2023, but not for an unlinked MRS. (See Table 4.2.) The increase would be due primarily to doses from at-reactor spent fuel management activities. For an unlinked MRS, the increase due to the delayed repository would be only about 20 percent because many activities, instead of being carried out at the reactors, would be performed at the MRS, where there would be a greater reliance on remote operations and remote handling facilities.

4. DOE and Commission Estimates

Table 4.4 compares the Commission's dose estimates for linked MRS and No-MRS systems with the U.S. Department of Energy (DOE) estimates. Although the Commission's dose estimates were based on methodology and assumptions different from DOE's, the differences between DOE and Commission results are quite small.

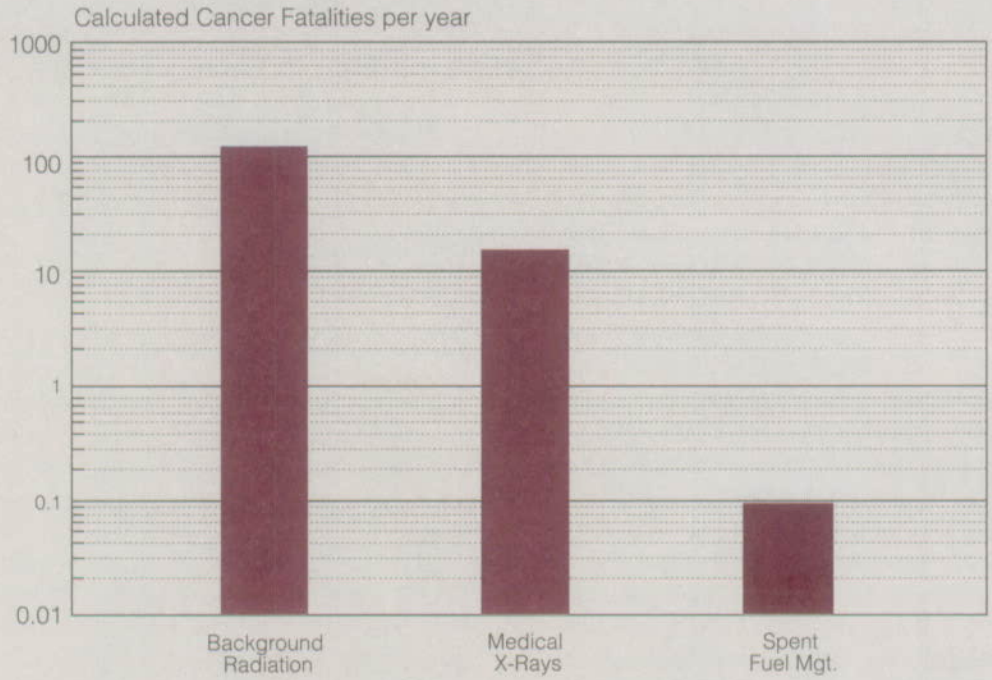
Commission estimates for occupational doses are somewhat higher than DOE estimates because the Commission used more conservative assumptions about doses to workers. Commission estimates of transportation doses to the public are higher than DOE estimates because: (1) the DOE estimates include loading and handling doses associated with transportation in the occupational doses for the facility where they are carried out rather than reporting them separately as the Commission did, and (2) DOE used unit risk factors developed by Argonne National Laboratory (ANL) for determining public dose from transportation, while the Commission used the modified Radtran III unit risk factors.[6] The ANL model produces reduced doses for truck shipments but much higher doses for rail shipments. (See Chapter Five for a discussion of the differences.) The Commission estimates that adding a Nuclear Waste Policy Amendments Act (NWPAA) linked MRS to the system would decrease the public dose by 4,600 person-rem (1.8 calculated cancer fatalities) and the occupational dose by 3,800 person-rem (1.5 calculated cancer fatalities). DOE estimates that adding an MRS to the system would decrease the public dose by 1,500 person-rem (0.6 calculated cancer fatalities) but increase the occupational dose by 7,300 person-rem (2.9 calculated cancer fatalities). In either case, the differences between the MRS and No-MRS systems are relatively small even over the 40-year period examined.

5. Variations in Assumptions

To determine the sensitivity of the dose estimates to changes in basic parameters and assumptions, the Commission performed sensitivity analyses for each of the three base cases (No-MRS, linked MRS, and unlinked MRS). The sensitivity analyses assumed the repository would start in 2013, but similar results would have been obtained if either of the other repository start dates had been used. The results of these sensitivity studies are shown in Table 4.5. (See Appendix H for a detailed list of the sensitivity analyses performed for this study.)

The sensitivity analyses clearly demonstrate that both public and occupational dose estimates would remain low

Figure 4.1—A Comparison of Calculated Cancer Fatalities From Natural Background Radiation, Medical X-rays, and Spent Fuel Management Activities



[a] Doses from natural background radiation and medical x-rays are calculated using annual dose rates from NCRP Report No. 93, "Ionizing Radiation Exposure of the Population of the United States." September, 1987, and an assumed exposed population of one million persons within a 50-mile radius of the MRS. Doses from spent fuel management activities are based on calculations by the MRS Review Commission staff. Cancer fatalities are calculated using conversion factors of four cancer fatalities for each 10,000 person-rem. the conversion factor is based on factors used in the EPA Draft Environmental Impact Statement for the Proposed NESHAPS (National Emission Standards for Hazardous Air Pollutants) for Radionuclides, EPA 520/1-89-005, February 1989, Vol. 1.

regardless of how the cases are modified. In fact, with few exceptions, the dose estimates in each sensitivity analysis are substantially the same as those in the base cases varied for the analysis. The one case worth noting is the use of 100 percent rail transportation, estimated to reduce the public dose by nearly 90 percent. The reduction is due almost entirely to reduced transportation doses and is discussed in Chapter Five. It is interesting to note that using dual-purpose casks does not appear to reduce doses significantly (dual-purpose casks are discussed in Section Two, Part E of this chapter), and rod consolidation at the reactors appears to increase occupational doses somewhat but does not affect public doses. (See Section Two, Part C for a discussion of rod consolidation risks.)

6. Findings

The Commission finds that only small public or occupational radiological risks are likely to result from management of spent fuel regardless of whether the system has an MRS.

Given the small absolute magnitude of the predicted risk and the uncertainty associated with the estimates of these risks, the Commission does not believe

Table 4.4—Total Life-cycle Doses in Person-rem for No-MRS and Linked MRS Systems

	NO-MRS		LINKED MRS (NWPAA)[a]	
Activity Center	Commission Estimates[b]	DOE Estimates[c]	Commission Estimates[b]	DOE Estimates[c]
Reactor	130/13,500[d]	<100/6,700	130/8,000	<100/6,700
MRS	—	—	4/300	<1/9,400
Repository	<1/8,400	<1/5,200	<1/8,400	<1/3,100
Transportation	7,900/4,200	3,600/[e]	3,400/5,600	2,100/[e]
Total	8,100/26,100	3,700/11,900	3,500/22,300	2,200/19,200

[a]MRS begins accepting spent fuel three years before repository start date.

[b]Commission estimates are based in each case on MARC analyses of systems with a 2013 repository start date.

[c]DOE estimates for MRS and repository are taken from PNL-6857, "Preliminary Dose Comparisons for the MRS Systems Study," April 1989. The No-MRS doses are from system configuration 1 (No-MRS, No Consolidation). The MRS doses are from system configuration 4 (Storage-only MRS, No Consolidation). Transportation estimates are taken from BMI/OTSP-07 "MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility," May 1989, p. 25, Table 16. Since PNL-6857 provides no dose estimates for at-reactor activities, at-reactor doses were taken from Department of Energy, "Monitored Retrievable Storage Submission to Congress," DOE/RW-0035/1-Rev. 1, Vol. II, February 1986, Table E-1, p. E-2. The repository in DOE's system handled only 63,000 MTU. MARC systems handled 86,800 MTU. To provide a basis for comparison, the numbers in this table are extrapolated from the actual DOE numbers.

[d]Public dose/occupational dose.

[e]In the DOE estimates, loading and handling doses associated with transportation are included in the facility (e.g., MRS) occupational doses rather than reported separately as was done in the Commission estimates.

these differences serve as a basis for discriminating among the alternatives.

B. Non-radiological Risks

1. Occupational

Workers will be exposed to non-radiological hazards during the construction, operation, and decommissioning of the facilities which manage spent fuel. The sources of these hazards are routine occupational accidents. The magnitude of these hazards is estimated by multiplying the labor hours projected to construct, operate, and decommission the facilities by a reasonable hazard exposure rate. The planned labor effort for spent fuel management operations at reactors was estimated using information from contractors the Commission engaged.[7]

Based on this analysis, the life-cycle non-radiological risk to workers is estimated to be about 40 fatalities and 2,500 lost-time accidents regardless of what scenario is assumed or whether there is an MRS in the system. The non-radiological risk is summarized in Table 4.6. The risks are nearly identical for the No-MRS and the MRS systems.

There are also non-radiological risks associated with the transportation of spent fuel; these are discussed in Chapter Five.

2. Public

With the exception of transportation risks, non-radiological risks to the public are minimal and were not considered in this analysis.

3. Findings

The Commission finds non-radiological occupational risk does not provide a basis for discriminating between MRS and No-MRS alternatives.

Table 4.5—Sensitivity Analyses of Total Life-cycle Doses (2013 Repository Start Date)

Cases[a]	TOTAL SPENT FUEL MANAGEMENT LIFE-CYCLE DOSES IN PERSON-REM		
	No-MRS	Constrained MRS[b]	Unconstrained MRS[b]
Base Case	8,100/26,100[c]	3,500/22,300[d]	3,500/17,000
Base Case Optimized for Risk	8,065/19,600	3,400/18,400[d]	3,400/15,200
Intrautility Transshipment Allowed	7,500/26,200	3,500/21,000	3,500/16,400
50% At-Reactor Consolidation	8,000/32,900	N.C.[f]	N.C.
Consolidation at the MRS	—	N.C.	3,800/17,200
MRS Inventory Limits:			
5,000 MTU	—	N.C.	3,500/24,600
15,000 MTU	—	—	3,500/19,100
30,000 MTU	—	N.C.	3,500/17,000
Alternative MRS Schedule Linkage[e]	—	3,500/20,000	N.C.
MRS Located in Central U.S.	—	N.C.	4,400/17,200
100% Rail Transportation	300/26,900	N.C.	N.C.
Dual-purpose Casks	8,100/22,100	N.C.	N.C.
Dual-purpose Casks and + 100% Rail	300/22,200	N.C.	N.C.

[a]Base case assumptions are discussed in Chapter 3, Section 3. All other cases use base case assumptions except as specifically noted.
[b]A constrained MRS is an MRS whose schedule is linked to the repository schedule. Except where noted, the constrained MRS is linked to the repository in a way which allows the MRS to begin operation three years before the repository. An unconstrained MRS has no schedule constraints but may have capacity constraints.
[c]Public dose/occupation dose.
[d]MRS linked to repository in accordance with the 1987 NWPAA.
[e]MRS linked to repository in a way which allows the MRS to begin operation five years before the repository.
[f]N.C. = Not calculated

Table 4.6—Total Life-cycle Non-radiological Occupational Risk for MRS and No-MRS Systems[a]

	MRS		NO-MRS	
Activity Center	Deaths	Injuries	Deaths	Injuries
Reactor	10	800	20	1,200
MRS	10	700	—	—
Repository	20	1,200	20	1,200
TOTAL	40	2,700	40	2,400

[a]The numbers would be approximately the same whether the MRS were linked or unlinked and regardless of the repository start date.

Section Two: Special Issues

Specific safety concerns raised during the Commission's deliberations include security risks, safety of spent fuel storage at reactors, safety of rod consolidation at reactors and at an MRS, safety at an MRS facility, and the use of dual-purpose casks.

A. Security Risks

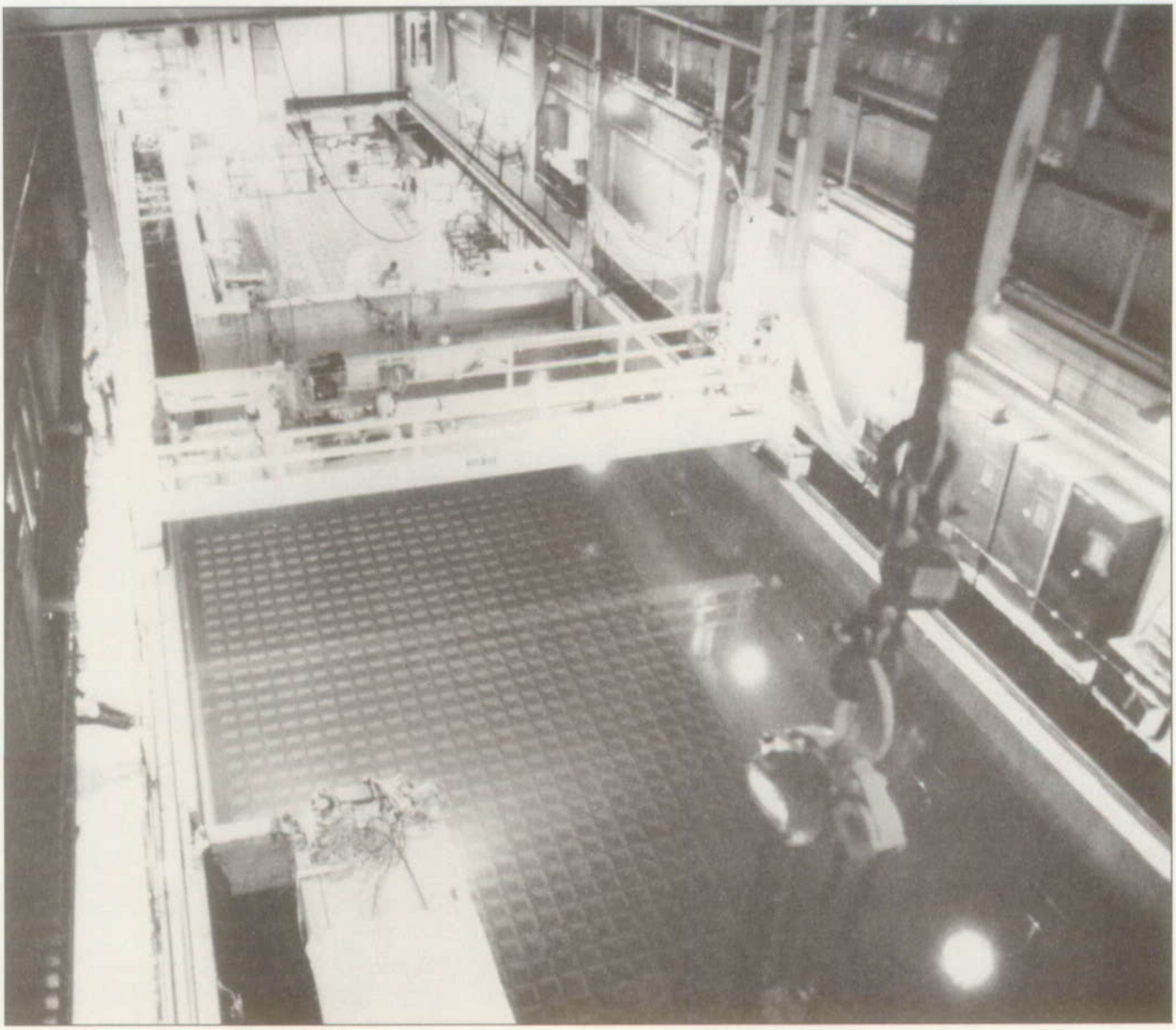
Safeguards are taken to preclude the potential for sabotage leading to release of radioactive materials to the environment and diversion of fissile material in the spent fuel for production of nuclear weapons. At the MRS Review Commission's request, the Nuclear Regulatory Commission (NRC), on May 25, 1989, briefed the Commission on safeguards issues associated with managing and storing of spent fuel.[8]

In response to Commission questions, the NRC staff stated that spent fuel stored either at individual reactor sites or an MRS is a poor target for sabotage or diversion and that there is no identifiable credible threat of sabotage or diversion of fissile material. In any case, the radiological consequences of sabotage would be low. Rod consolidation, which involves removing spent fuel rods from the fuel assemblies, could produce some compromise of accountability, but this would be small and acceptable. The NRC staff also said there is no significant concern about the security of spent fuel shipments. A 1986 NRC staff review of the conceptual design of the safeguards to be provided at the MRS indicated that NRC safeguards requirements can be met.[9]

A related issue of concern to some who testified at the Commission's public hearings was that storing spent fuel at an MRS would make reprocessing an attractive option, and this might increase the risk of diversion of fissile materials.[10] Reprocessing in the United States, however, appears extremely unlikely at this time because it is not economical. In any case, there appears to be little connection between MRS storage of spent fuel and a decision to reprocess, since spent fuel stored at reactors is also available for reprocessing, and most spent fuel would continue to be stored at reactors even if there were an MRS in the system.[11]

Analysis of security issues must take complicated concerns into account and requires access to classified information. Independent assessment of these concerns is difficult. **The Commission defers to the NRC's expertise and accepts its assessment. Based on the NRC assessment, safeguards risks associated with spent fuel at a reactor, at an MRS, or in transit appear so small that**

Figure 4.2—An Example of a Spent Fuel Pool



Source: Virginia Electric Power Company

they are not a serious consideration in comparing spent fuel management alternatives.

B. Storage at Reactors

1. Storage at Operating Reactors

The spent fuel management system is not totally integrated; that is, spent fuel storage and management operations at reactors are under the control of the individual utilities, while transportation, management, and disposal of spent fuel after it leaves reactor sites are under DOE control. There are approximately 100 operating reactors at about 70 sites managed by more than 50 different utilities.[12] Storing spent fuel at a central DOE facility could enhance safety because the spent fuel would be under the control of management and staff whose primary task is its safe storage and management. Centralized control of spent fuel may also provide a potential safety benefit because it increases system compatibility.

As the repository start date is delayed and spent fuel pools (see Figure 4.2) fill up, more reactors are expected to turn to spent fuel management operations (such as dry cask storage, transshipment, and rod consolidation) that were not contemplated when the reactors were designed. Such operations could divert workers' and managers' attention from their primary duty, operating the reactors, because of increased attention to spent fuel management, or because of accidents (such as contamination of the spent fuel pool) resulting from such operations.

However, spent fuel management operations have been safely carried out at reactors for many years under NRC regulatory control and by trained personnel. Once spent fuel has been removed from the reactor core, spent fuel handling and storage activities are separate from those activities associated with the production of electricity. Although the inventory of spent fuel at reactors is increasing, there is no reason to believe that safe management of the fuel cannot continue or that the fuel will interfere significantly with safe reactor operations.

Dry storage of spent fuel at reactors is a passive and safe process. Once spent fuel is placed in dry storage casks or bunkers, it requires no additional care except periodic monitoring and security to assure that the casks or bunkers do not deteriorate, radioactive material is not released to the environment, and no unauthorized access to the spent fuel storage area occurs.

It appears that most, if not all, reactor sites can safely store all of the spent fuel that would be generated during the reactor's 40-year operating life. In a study for the Commission of spent fuel storage needs and at-reactor capability, Ebasco concluded that most operating reactors can provide additional dry spent fuel storage at their sites on a schedule corresponding with their needs. This storage can be expanded as necessary to meet life-of-plant storage requirements (or beyond, in the event of an extended plant life).[13]

At most sites, life-of-plant storage can be accomplished by reracking spent fuel pools and using dry storage. Where sufficient space for dry storage does not exist, utilities may be able to consolidate spent fuel to create additional storage capacity in the spent fuel pool (although at some boiling water reactors this would be limited by weight restrictions on the spent fuel pool). As discussed below, there is no reason why such rod consolidation could not be carried out safely. Some utilities could solve their spent fuel storage problem temporarily by transshipping spent fuel from one utility-owned reactor to another. However, this cannot be viewed as a long-term solution since it does not increase total at-reactor storage capability.

Although neither the Commission nor its contractors identified specific reactors which would have storage problems during the full operating life of the plant, it is possible that technical limitations at a few reactors would make it difficult to store all of the spent fuel generated during the reactor's operating life. It is also possible that public opposition could delay or halt the building of additional storage at a reactor. Therefore, it may be prudent to provide some away-from-reactor storage for those few utilities which may be faced with such a problem, rather than risk forced, premature shut down of the plants. More definitive information on reactors' storage capability should be available when DOE completes its present study on this issue.[14]

2. Storage At Shutdown Reactors

The Commission examined whether storing spent fuel at permanently shutdown reactors could create safety problems. Although a few reactors may shut down before their licenses expire, and a few licenses expire before 2009, the bulk of the reactors now operating will reach the end of their presently licensed operating lives between the years 2009 and 2030, as shown in Figure 4.3.

Table 4.7 and Figure 4.4 show that substantial amounts of 5-year-old spent fuel[15] will begin to accumulate at shutdown reactors after 2015 if there is no facility available to accept spent fuel. The NRC, in its "Waste Confidence Decision Review,"[16] has recently concluded that spent fuel can be stored safely and without any significant environmental impacts for at least 30 years beyond the expiration of a reactor's operating license at the reactor's spent fuel storage basin or at an on-site, independent spent fuel storage facility, or for a total of 100 years if an extended period of reactor operations is included.

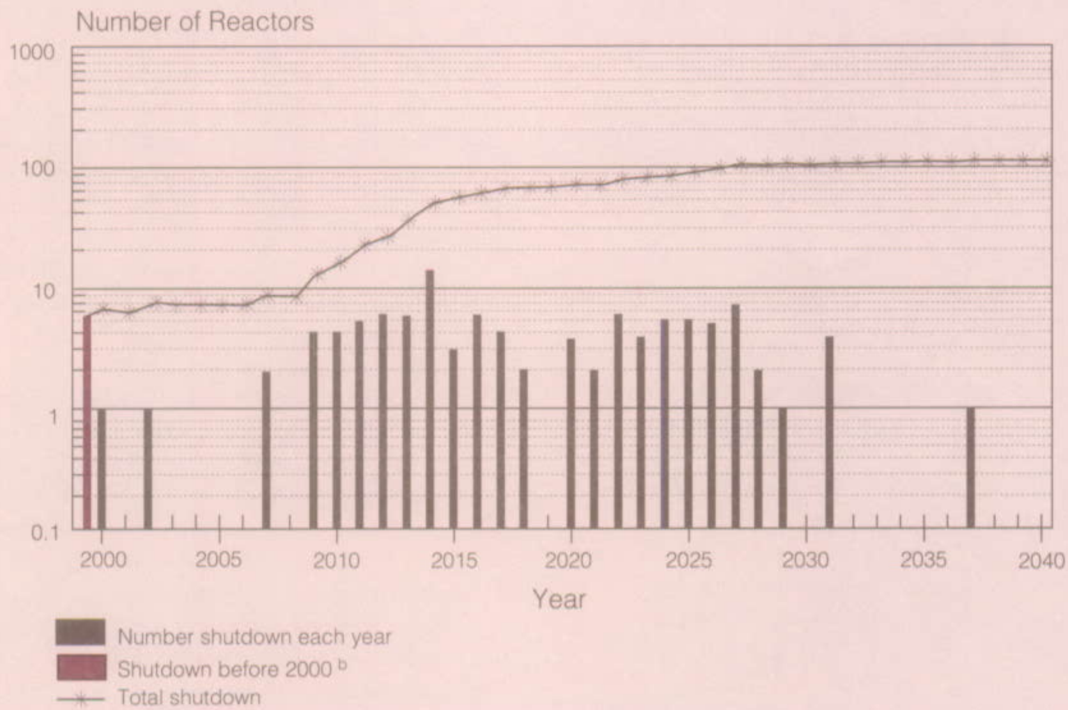
However, maintenance of spent fuel on-site after reactor shutdown is not without consequence. The activities which the licensee must carry out to meet NRC requirements for the various decommissioning options vary depending on the types and amounts of radioactive material remaining on-site after the plant shuts down.[17] If spent fuel has been removed from the site, these requirements are usually minimal. If spent fuel is kept at the site:

- security must be maintained to safeguard the spent fuel;[18]
- the integrity of the spent fuel storage system must be maintained;[19] and
- a Certified Fuel Handler must supervise spent fuel handling.[20]

As a result of these requirements, storing spent fuel on-site after reactor shutdown is costly to the utility. Maintaining spent fuel at a shutdown reactor is expected to cost between $2 to $3 million more per site per year than if all spent fuel were removed.[21] To avoid these costs, utilities will want to remove the spent fuel from the site as soon as possible. Therefore, it is likely that utilities would opt to remove all spent fuel by the fifth year after reactor shutdown when the last spent fuel discharged from the reactor becomes eligible for DOE to remove it.[22]

Following reactor shutdown, trained reactor personnel

Figure 4.3—Shutdown Commercial Light Water Power Reactors (LWR)[a]



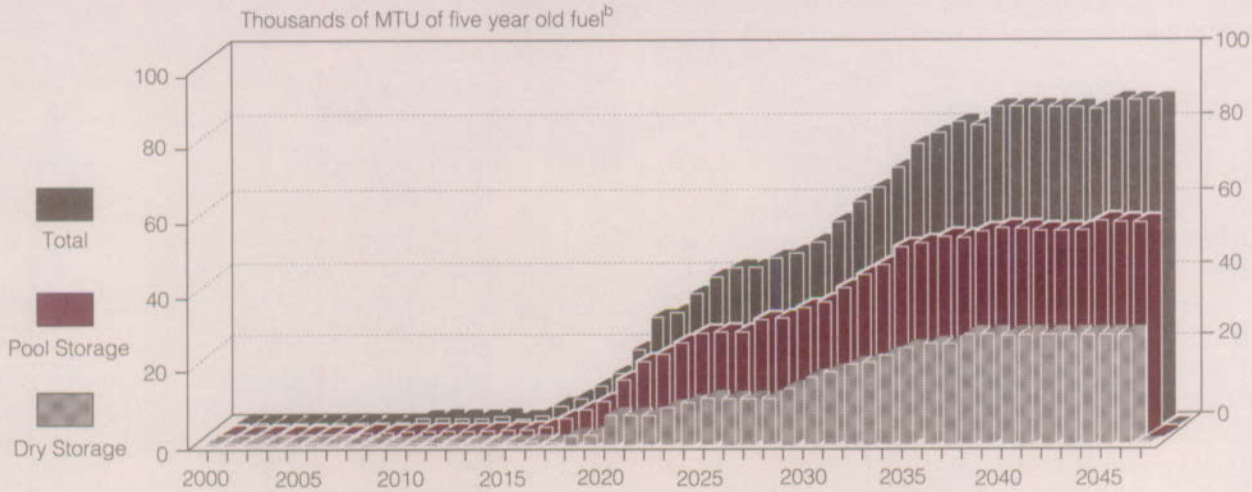
a Assumes all reactors will be shut down 40 years after initial reactor startup date.
Data from DOE/RL-88-34, "Spent Fuel Storage Requirements 1988," October 1988, Table A.1.

b Includes only shutdown commercial reactors which still have spent fuel stored on-site.

would probably seek employment where their skills would be more useful. Monitoring the stored fuel and maintaining security would probably be routine and monotonous and could be carried out as a part-time responsibility by persons whose principal duties were elsewhere. Under such conditions, these operations might not be performed as well as expected, so there could be some risk that spent fuel storage and subsequent handling to prepare it for shipment to the repository would be performed under less than ideal conditions. This is unlikely, however, given the strict regulatory requirements under which the spent fuel must be stored and handled. Also, utilities may be able to hire outside firms with expertise in spent fuel handling to conduct some of these activities.

A central interim storage facility would address these safety concerns because it would have a group of trained and experienced fuel handlers, health physicists, and security staff available at all times. Providing the necessary personnel at a single site rather than at individual utilities would be more efficient and result in substantial cost savings to the utilities. Furthermore, since the workers would handle spent fuel daily, they would be more experienced in performing routine handling operations that would occur only infrequently at a shutdown reactor and better able to handle emergencies that might occur. Therefore, although spent fuel can be stored safely at individual sites, early waste acceptance from shutdown reactors could provide benefits.

Figure 4.4—Spent Fuel Accumulation at Shutdown Commercial Light Water Power Reactors[a]



[a] Assumes all spent fuel stays at reactors indefinitely. Accumulation figures can be found in Table 4.7.
[b] Five year old fuel is used because under the existing contracts between the utilities and DOE, generally, DOE will not begin to accept spent fuel from the utilities until it has aged five years since its discharge from the reactors. 10 CFR 961.11, Appendix E, Section B, paragraph 3.

Table 4.7—Spent Fuel Accumulation at Shutdown Commercial Light Water Power Reactors[a]

MTU of Five Year Old Fuel[b]

YEAR	DRY STORAGE	POOL STORAGE	TOTAL
2000	0	500	500
2005	0	500	500
2010	0	1,500	1,500
2015	500	4,000	4,500
2020	7,500	21,000	28,500
2025	12,000	29,000	41,000
2030	19,500	40,000	59,500
2035	27,000	54,000	81,000
2040	29,000	55,500	84,500
2045	30,000	57,000	87,000

[a]Assumes all spent fuel stays at reactors indefinitely. Accumulation shown graphically in Figure 4.4.
[b]Five-year-old fuel is used because under the existing contracts between the utilities and DOE, generally DOE will not begin to accept spent fuel from the utilities until it has aged five years since its discharge from the reactors. 10 CFR 961.11, Appendix E, Section B, paragraph 3.

On balance, the Commission finds that, under normal circumstances spent fuel can be stored safely at reactor sites, using either pool or dry storage, during the operating life of the reactor and for up to 30 years thereafter. However, it may be prudent to provide a central interim storage facility where spent fuel would be under the full-time care of trained personnel and management whose exclusive responsibility is the fuel's safe storage and handling.

C. Rod Consolidation

Another safety issue is spent fuel consolidation. The Commission studied whether spent fuel consolidation can be carried out safely on a production scale at reactors, at an MRS, or at the repository and whether there are system benefits to be obtained from consolidation.

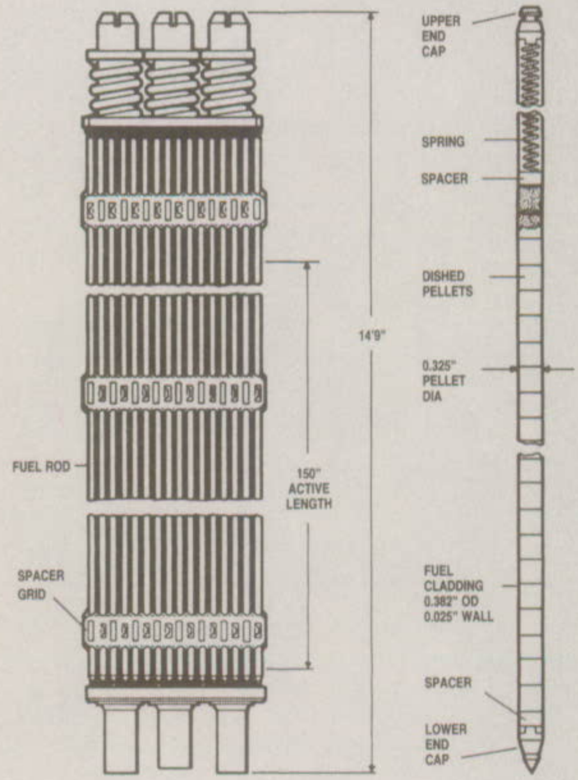
During rod consolidation, the non-fuel-bearing components (upper and lower fuel-assembly tie plates, assembly spacer grids, and any other assembly structural members) are removed from spent fuel assemblies, reduced in volume, and stored. The fuel rods are collected and closely packed into a bundle inside a canister to achieve volume reduction, thereby potentially reducing the space required for storage, transportation, or disposal. Figure 4.5 shows a typical fuel assembly and fuel rod.

Until recently, DOE, when comparing MRS and No-MRS options, has assumed consolidation would be a part of the spent fuel management system. In addition, a number of utilities have considered fuel rod consolidation as a way to increase spent fuel pool capacity.

To ascertain whether rod consolidation would affect system risk substantially, the Commission analyzed a No-MRS case in which 50% of all spent fuel is consolidated at the reactor site[23] and an MRS case in which spent fuel which passes through the MRS is consolidated at the MRS. (See Table 4.8.) In the No-MRS case, public doses remain essentially the same whether there is at-reactor consolidation, but there is a small increase in occupational dose at the reactor. In the MRS case, consolidation at the MRS produces no significant change in either public or occupational risk.

The Commission sponsored an independent evaluation of the risks, benefits, and economic costs of rod consolidation at reactors, at an MRS facility, and at the repository.[24] In assessing the risks, factors considered were the maturity of the technology, contamination control, generation of secondary wastes, worker exposure, criticality, potential accidents, and, for consolidation performed at the reactor, potential adverse impacts on reactor safety. This assessment concluded that both wet consolidation (which would be used at reactors) and dry rod consolidation (which would be used at an MRS or repository) are technically

Figure 4.5—Fuel Assembly and Fuel Rod



Source: Nuclear Regulatory Commission

TABLE 4.8—Comparison of Total Spent Fuel Management Life-cycle Doses for Systems with and without Consolidation (2013 Repository Start Date)

	NO-MRS		UNLINKED MRS[a]	
Activity Center	No Consolidation	Consolidation[b] At Reactors	No Consolidation	Consolidation[c] at MRS
Reactor	130/13,500[d]	130/21,500	130/1,900	130/1,900
MRS	—	—	5/600	10/900
Repository	≤1/8,400	<1/8,400	<1/8,400	<1/8,400
Transportation	7,900/4,200	7,900/2,900	3,400/6,100	3,700/6,000
Total	8,000/26,000	8,000/32,000	3,500/17,000	3,800/17,200

[a]An unlinked MRS was selected to provide an upper bound for the radiological effects resulting from consolidation at the MRS. The MRS is assumed to begin operation in the year 2000.
[b]Assumes 50% of all spent fuel consolidated at reactors.
[c]Assumes all fuel which goes through the MRS is consolidated.
[d]Public dose/occupational dose.

feasible, but are still in the developmental stage. The NRC staff, in its 1986 evaluation of a draft of DOE's MRS proposal later submitted to Congress, essentially came to the same conclusion concerning consolidation at the MRS.[25] For wet consolidation at reactors, additional staffing requirements and potential pool contamination are key utility concerns. For dry consolidation at an MRS or repository, production rate and generation of secondary wastes are potential problems.[26]

In its initial MRS proposal, DOE stated that "consolidation at an MRS offered system advantages by providing more compact packages of waste, thus reducing the number of packages to be handled, transported, and put underground."[27] However, after conducting a series of system studies reexamining the role of the MRS in the waste-management system, DOE now finds no significant benefits to be obtained from rod consolidation at the MRS. In testimony presented to the Commission DOE stated, "The DOE will not presume at this point that the spent fuel will be subjected to any operations like consolidation because there is no clear incentive for such operations...The selection of the Yucca Mountain site has allowed the DOE's studies to focus on the economics of various waste-package concepts for that site, and these studies have not identified sufficient advantages for consolidation to warrant its use at present."[28] Therefore, although rod consolidation probably can be done safely at an MRS, there appears to be little incentive at present to introduce the potential risks associated with this immature technology into the MRS facility. This could change if, for example, increases in projected disposal packaging costs provide greater incentive to reduce the number of packages to be emplaced in the repository.

At-reactor rod consolidation also can apparently be done safely,[29] but has yet to be demonstrated at the commercial scale necessary to make it an attractive alternative to dry cask storage for the utilities. Utilities which have tried rod consolidation have opted for dry storage instead.[30]

The Commission finds that rod consolidation has yet to be demonstrated on a production-rate basis. Whether performed at reactors or at an MRS, rod consolidation, like any other technology, poses some health and safety risks, although these are estimated to be small. Decisions on whether rod consolidation would provide sufficient benefits to the waste management system as a whole to justify the risks and costs must await further development of the technology, the shipping casks, and the repository. Until the need for and feasibility of rod consolidation for the waste manage-

ment system are determined, utilities are expected to continue to examine the benefits and costs of at-reactor rod consolidation and make decisions appropriate to their individual needs.

D. Safety of the MRS Facility

The Commission considered whether adding an MRS facility would introduce substantial additional risks or environmental impacts into the spent fuel management system.

A number of people expressed concern to the Commission about the potential safety and environmental impacts associated with adding another facility to the system.[31] Most of these concerns relate to transporting spent fuel to and from the MRS. However, the State of Tennessee, which extensively analyzed the MRS that DOE planned to site near Oak Ridge, opposed siting the MRS there, but not on safety or environmental grounds.[32]

The NRC staff evaluated the DOE proposal for an MRS and concluded that (1) the nature of the operations involved—passive storage and relatively simple mechanical processes—indicates the MRS would create a limited potential for accidents or adverse consequences; (2) the MRS conceptual design appears reasonable from the standpoint of public health and safety, and (3) it appears from the conceptual design that NRC requirements can be met.[33] The Commission agrees with this assessment.

E. Dual-purpose Casks

The State of Tennessee has proposed an integrated No-MRS system which it claims is superior to the integrated MRS system proposed by DOE. The centerpiece of the Tennessee proposal is the use of dual-purpose casks. Dual-purpose casks are designed to be used for dry storage and subsequent shipment of spent fuel to the repository. (See Figure 4.6.) One of the principal advantages claimed for dual-purpose casks is that using them reduces the number of times spent fuel must be handled.[34] As a result, occupational radiation exposure to workers would be reduced.[35]

A No-MRS case using dual-purpose casks was analyzed using a computer code called MARC (MRS Review Commission's Analysis of System Risk and Cost—see Chapter Three, Section Two and Appendix G). The occupational dose was reduced by about 15% from 26,000 to 22,000 person-rem due to reduced cask loading and handling doses at the reactor. (See Table 4.5.) However, the public dose remained essentially the same.

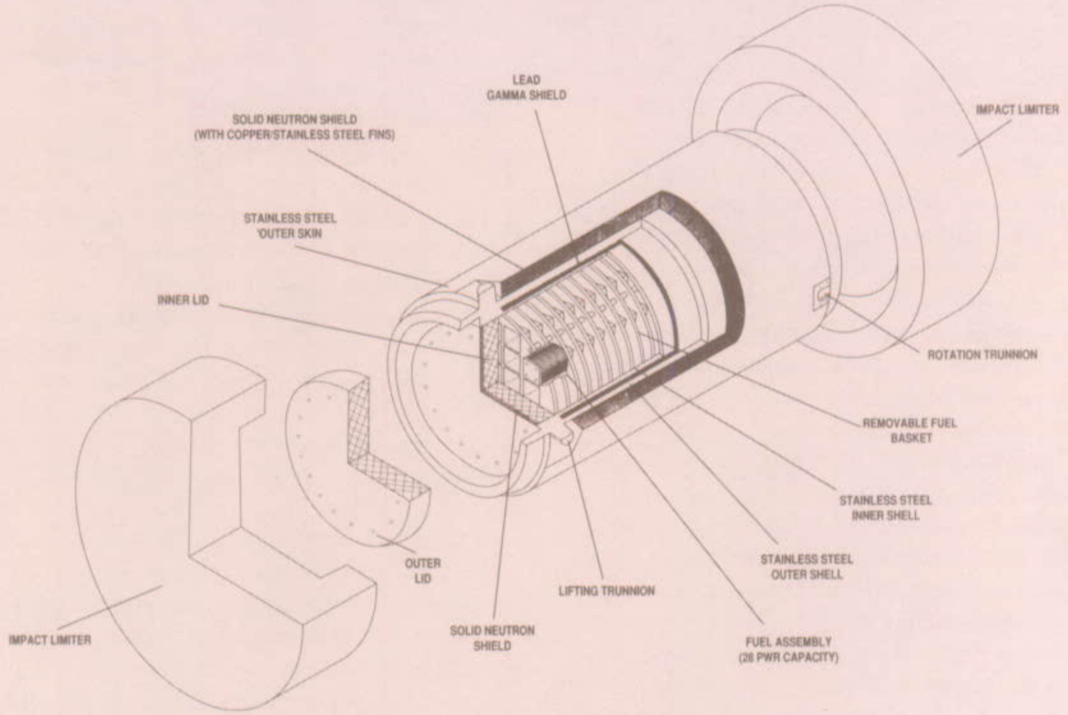
There are some potential problems with using dual-purpose casks. First, such casks are not currently approved for use in the United States, although they are approved for use in the Federal Republic of Germany and their use is being considered by other European countries.[36] (See Appendix D.) The NRC expects to receive and complete review of an application for certification of a dual-purpose cask within the next few years. However, there can be no assurance now that certification will be forthcoming. Dual-purpose casks will have to be certified under two sets of regulations, 10 CFR Part 71 (transportation) and 10 CFR Part 72 (storage). Transportation requirements are generally more stringent than those for storage, and transport casks must be recertified every five years. A concern regarding whether a cask can be designed to meet both sets of requirements is deterioration of the cask seal during long storage periods before transportation. However, it is expected that dual-purpose casks will have a double lid and two sets of seals so that the outer seals can be tested and replaced, if necessary, without opening the cask or removing the spent fuel to ensure containment after long periods of storage.

Another potential problem is physical deterioration of the basket which holds the fuel rods in place in the cask. The principal concerns are: (1) whether the cask and basket will maintain their integrity throughout prolonged storage periods, perhaps up to 40 years, before transport, and (2) whether the NRC will have sufficient confidence in this integrity to allow transport without requiring that the casks be opened for inspection. If dual-purpose casks have to be opened for inspection before shipping, their apparent risk advantages would be substantially reduced.

The Commission finds that the use of dual-purpose casks in either an MRS or a No-MRS system should be seriously considered because the casks could require less handling and create less occupational exposure. However, dose reductions are small and, given the uncertainties cited above, the dose reductions from using dual-purpose casks do not provide a basis for discriminating between MRS and No-MRS options.

(For additional discussion of dual-purpose casks, see Chapter Five, Section One, Part B.)

Figure 4.6—A Dual-purpose Cask



Source: Nuclear Assurance Corporation

Section Three: Environmental and Socioeconomic Effects

This section discusses the environmental impacts which might be significant in comparing spent fuel management systems with and without an MRS. These include the potential environmental impacts associated with dry storage of spent fuel at reactor sites and construction, operation, and decommissioning of an MRS facility.

A. Effects of Storage

1. At Reactors

The environmental impacts associated with at-reactor pool and dry storage of spent fuel assemblies are expected to be insignificant. Dry storage will involve land use. However, most utilities have sufficient land to accommodate dry storage, and land acquisition was considered under the environmental impact assessment for the original reactor licensing actions.

When licensing at-reactor operations, the NRC must consider environmental impacts. The NRC has already licensed the dry storage of spent fuel at the Virginia Power Company's Surry Nuclear Power Station and at Carolina Power and Light Company's H.B. Robinson Nuclear Project. In each case, the NRC found no significant environmental impact.

2. At an MRS Facility

DOE has evaluated the range and types of environmental effects of an MRS and submitted its evaluation to Congress.[37] The information in this section is based on that study.

DOE evaluated the environmental impacts of six MRS site-design combinations: three candidate sites with two design concepts at each. The two design concepts were based on identical receiving and handling concepts but different spent-fuel storage concepts: sealed storage cask and field drywell. Since environmental impacts are to some extent site specific, it is impossible to characterize accurately all of the environmental impacts until the MRS site has been identified. However, the DOE evaluation was designed to compare the environmental effects of specific site-design combinations and to reveal risks or impacts of elements of the MRS facility design for three different types of sites. This provides a basis for drawing general conclusions about the expected environmental impact of an MRS. Based on this evaluation, DOE found no design features for either storage concept that created significant adverse impacts or any that resulted in significantly different effects across the three candidate sites.

Preconstruction and construction activities are expected to degrade, temporarily, the ambient air quality in the immediate vicinity of the site. Short-term total suspended particulate standards may be exceeded due to dust from land disturbance and heavy vehicle traffic. No significant aiborne emissions are anticipated from constructing and operating an MRS facility.[38]

Waste heat generated by the facility is expected to include about 23 megawatts (MW) from heat generated from the radioactive decay of spent fuel in the storage areas and 25 MW from the facility's heating and air conditioning cooling tower.[39] No perceptible changes in the downwind environment are anticipated. Decommissioning an MRS is not expected to include major demolition or regrading. Therefore, impacts from decommissioning activities are expected to be negligible. During construction, water quality could be temporarily degraded from high-suspended solids content of the runoff. Settling solids in runoff ponds before discharging the water to surface waters will mitigate such degradation. The MRS facility will be designed so that radioactive waterborne effluents are not discharged into the environment. Effluents from wastewater treatment are expected to meet all State and EPA standards for industrial, municipal, and domestic wastewater disposal.

The largest ecological impact will be the clearing of land and subsequent loss of this land to production and ecological processes. Up to 320 acres will be needed, depending on the functions to be carried out at the MRS.

B. Socioeconomic Effects

The major socioeconomic impact resulting from the development of any site-design combination is the loss of the site for potential commercial development, with resulting potential loss of additional tax revenues. In the absence of offsetting financial compensation, any demands the MRS facility or its employees create on public services would have to be met by State, Tribal, and local government revenues. An adverse image for the local area, either through perpetuation of economic uncertainty or through fear of environmental hazards, could also affect commercial development. Although little actual health risk from radiation exposure is expected, the MRS facility may generate socioeconomic impacts because of the public's behavioral reactions to the perceived risk (the so-called "stigma effect"). This is discussed in more detail in Chapter Seven.

The jobs and incomes the MRS creates would attract people into the area and create demands for housing, schools, community services, and infrastructures such as utilities, roads, and sewers.

Aesthetic impacts include projected noise levels, principally during construction, and visual impacts. Distance and natural barriers would attenuate noise. Visual impacts would be similar to that of any multi-story building complex. The largest building at the facility would be the Receiving and Handling (R&H) building, a concrete structure 97 feet (about 9 stories) high. The main stack, 165 feet above the ground level, would be on top of the R&H building. The 36-acre storage area would be an array of concrete casks about 22 feet tall.[40]

In summary, based on the DOE environmental analysis, the environmental impacts of an MRS are expected to be similar to those associated with constructing and operating any similarly sized industrial facility.

C. Findings About Environmental and Socioeconomic Effects

The Commission finds that the environmental impacts associated with spent fuel management will be small and within regulatory limits for all spent fuel management alternatives considered, regardless of whether they include an MRS.

Section Four: Findings

The Commission finds that occupational, public, and environmental effects associated with storing and managing spent fuel are small and are expected to be within appropriate regulatory limits regardless of the spent fuel management alternative selected or the repository start date assumed. The Commission also finds that the differences in risks among the alternatives considered are so small they do not provide a basis for discriminating between MRS and No-MRS alternatives.

Chapter Four Notes

1. Person-rem is a unit of population dose equivalent obtained by multiplying the dose equivalent in rem by the population exposed. In the International System of Units, this would be expressed in person-sieverts.

2. Estimates of the number of cancer fatalities resulting from exposure to ionizing radiation vary from about 100 to several hundred fatalities per million person-rem. The estimate of 400 fatalities per million person-rem used in this report is based on conversion factors used in the U.S. Environmental Protection Agency's (EPA) Draft Environmental Impact Statement for Proposed NESHAPS (National Emission Standards for Hazardous Air Pollutants) for Radionuclides, EPA 520/1-89-005, February, 1989, Vol.1, see, for example, p. 6–15.

3. The total life cycle dose from the MRS is about four person-rem (see Table 4.4). Assuming a 40-year life for the system, the yearly dose would be 0.1 person-rem.

4. Dose from natural background radiation: 0.3 rem/year x one million persons exposed = 300,000 person-rem. Dose from medical x-rays: 0.039 rem/year × one million persons exposed = 39,000 person-rem. The 0.3 rem/year and 0.039 rem/year figures are taken from the National Council on Radiation Protection Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," September 1987, p. 53. The exposed population of one million persons is based on an assumed population within a 50-mile radius of the MRS—roughly equivalent to the estimated population for the previously proposed site near Oak Ridge, Tennessee. This same population estimate was used to calculate the population dose from activities at the MRS.

5. The percent of in-transit doses to the truck driver and train crew was estimated by performing two runs on the MARC computer model (one for an MRS system and one for a No-MRS system), with the program modified so that it would not calculate doses to the driver and crew.

6. Modifications to RADTRAN III are described in the June 8, 1989, letter and attached draft report from Thomas H. Isaacs, Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, to Jane A. Axelrad, Executive Director, MRS Review Commission. ("Development of RADTRAN-based Radiological Unit Risk Factors for Use in TRICAM," May 31, 1989).

7. Golder Associates, "Safety and Environmental Impacts for Alternative Spent Fuel Management Options," July 1989.

8. McCorkle, George, Deputy Director, Division of Safeguards and Transportation, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Transcript of Briefing Before the Monitored Retrievable Storage Review Commission, May 25, 1989 **(Hereafter cited as Briefing Transcript, May 25, 1989).**

9. Nuclear Regulatory Commission, "Staff Evaluation of U.S. Department of Energy Proposal For Monitored Retrievable Storage," NUREG-1168, March 1986 **(Hereafter cited as NUREG-1168).**

10. For example, see Johnsrud, Judith, Ph.D., Director, Environmental Coalition on Nuclear Power, and Research Director, Food and Water Inc., Transcript of Monitored Retrievable Storage Review Commission Public Hearings **(Hereafter cited as Hearings Transcript)**, December 1, 1988, p. 139; Bechtel, Dennis, Coordinator, Clark County Comprehensive Planning Department, Hearings Transcript, January 9, 1989, p. 47; Fulkerson, Robert, Executive Director, Citizen Alert, Hearings Transcript, January 9, 1989, p. 289; Drey, Laura, News Editor, Coalition for Alternatives to Shearon Harris, Hearings Transcript, February 16, 1989, pp. 170–171, 179–180, 183.

11. Spent fuel is generated at a rate of about 2,000 metric tons of uranium (MTU)/Yr. An MRS with a 15,000 MTU limit, as now specified in the NWPAA, would be able to hold only 40 percent of the 40,000 MTU expected to be accumulated by the year 2000 and only 25 percent of the 60,000 MTU expected to be accumulated by 2010.

12. On December 31, 1988, there were 107 light water reactors (70 pressurized water reactors and 37 boiling water reactors) operating in the United States. Department of Energy, "Commercial Nuclear Power 1989, Prospects for the United States and the World," DOE/EIA-0438(89), Appendix C.

13. Ebasco, "Spent Fuel Storage Need and At-Reactor Capability Study," June 1989, pp. 5–10.

14. The Department of Energy's Office of Civilian Radioactive Waste Management is sponsoring the Facility Interface Capability Assessment (FICA) Project. The project objectives are to determine and document existing and planned facility capabilities to store and ship spent fuel and identify facilities where possible interface changes could benefit the Federal waste management system. Nuclear Assurance Corporation, the contractor performing the study, will visit 76 sites including all 122 facilities from which commercial spent fuel will be accepted by the Federal waste management system. The project is scheduled to be completed in early 1990.

15. The fuel's age is important because, under the existing contracts between the utilities and DOE, generally, DOE will not accept spent fuel from the utilities until five years after its discharge from the reactors. 10 CFR 961.11, Appendix E, Section B, paragraph 3.

16. U.S. Nuclear Regulatory Commission, Waste Confidence Decision Review, 54 FR 39767 (September 28, 1989). (See Chapter 3, Note 20.)

17. Based on personal communications between James C. Malaro, MRS Review Commission staff and the following staff of the Nuclear Regulatory Commission: Peter Ericson, Project Manager, Decommissioning and Environmental Project Directorate, Office of Nuclear Reactor Regulation (August 22, 1989); Michael Bell, Chief, Regulatory Branch, Division of Low Level Waste Management and Decommissioning, Office of Nuclear Material Safety and Safeguards (August 28, 1989); and Philip Ting, Section Leader, Requirements and Oversight Section, Domestic Safeguards and Regional Oversight Branch, Division of Safeguards and Transportation, Office of Nuclear Material Safety and Safeguards (August 30, 1989); and on examination of the following documents: a) Amendment 23 to License for Humboldt Bay Unit 3 authorizing SAFSTOR until November 9, 2015 (Docket 50-133, July 19, 1988) and b) Amendment 3 to License for Fermi 1 extending SAFSTOR until March 20, 2025 (Docket 50-16, April 28, 1989.)

18. There are no generic safeguards requirements for storing spent fuel at shutdown reactors. Safeguards requirements are tailored to each plant's specific circumstances in accordance with the requirements of 10 CFR Part 73, "Physical Protection of Plants

and Materials." Specific security requirements are withheld from public inspection because public disclosure could increase a plant's vulnerability to sabotage. However, Pacific Northwest Laboratory, in estimating SAFSTOR costs, assumed a security force consisting of a minimum of five armed personnel per shift would be maintained as long as the spent fuel remained on-site. NUREG/CR-0672, Addendum 1, "Technology, Safety, and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, Effects on Decommissioning of Interim Inability To Dispose of Wastes Offsite," July 1983, p. 3.3.

19. For the spent fuel pool, this includes maintaining water level, quality, temperature, and circulation; maintaining a supply of make-up water for the pool; and conducting a surveillance program to assure the continued integrity of neutron-absorbing materials used to control criticality.

20. A Certified Fuel Handler is someone who has been trained to handle fuel (including spent fuel) at the site for which he or she is certified. Humboldt Bay, for example, has an NRC-approved program for training and certifying fuel handlers. Although removing and disposing of spent fuel is considered an operational activity, neither storage of spent fuel at a reactor site after reactor shutdown nor subsequent removal of spent fuel from the site requires the presence of a trained reactor operator.

21. Pacific Northwest Laboratory estimates the cost of maintaining spent fuel storage at a site following reactor shutdown to be $2.2 million per year for a one or two pool site and $2.7 million per year for a three pool site. This cost is assumed to be independent of the quantity of spent fuel stored and is expected to be significantly less if the shutdown reactor is collocated with an operating reactor. Pacific Northwest Laboratory, "MRS Systems Study Task G Report," PNL-6876, April 1989, p. 3.19.

22. See Note 15.

23. It was assumed that all spent fuel was consolidated at each reactor which could achieve life-of-plant storage in the spent fuel pool through consolidation.

24. Ebasco, "Rod Consolidation Costs, Risks, and Benefits Study," June 1989 **(Hereafter cited as Ebasco, Rod Consolidation).**

25. NUREG-1168, p. 2.

26. Another possible concern is whether rod consolidation might raise the danger of criticality of the fuel. However, criticality during consolidation or with storage or handling of consolidated fuel appears extremely unlikely. Ebasco, Rod Consolidation, pp. 3–13 and 4–10.

27. Department of Energy, "Report of the Task Force on the MRS/Repository Interface," DOE/RW-0044, February 1986, p. 2–1.

28. Thomas H. Isaacs, Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE Position on the Monitored Retrievable Storage (MRS) Facility," Prepared Remarks before the Monitored Retrievable Storage Review Commission, May 25, 1989 **(Hereafter cited as Isaacs, Prepared Remarks, May 25, 1989)**, pp. 6–7.

29. Department of Energy, "Final Version Dry Cask Storage Study," DOE/RW-0220, February 1989, p. I–95; Ebasco, Rod Consolidation, pp. 3–20.

30. The four utilities are Duke Power Company (Oconee Units 1 and 2), Maine Yankee Atomic Power Company (Maine Yankee), Northeast Utilities (Millstone 2), and Northern States Power (Prairie Island). Ebasco, Rod Consolidation, Section 3.1.

31. For example, see Lowery, Leon, Legislative Representative, Environmental Action, Hearings Transcript, December 2, 1988, pp. 351–352; Clarke, James McClure, U.S. House of Representatives, 11th District, North Carolina, as presented by Claudine Cremer, District Assistant, Hearings Transcript, February 17, 1989, pp. 262, 267; Sharp, Jane, Board Member, Conservation Council of North Carolina, Prepared Remarks, February 16, 1989, pp. 1–2.

32. McWherter, Ned, Governor, State of Tennessee, "Tennessee's Position on the MRS: Final Comments to the Monitored Retrievable Storage Review Commission," July 20, 1989 **(Hereafter cited as Tennessee's Final Comments)**, p. 4.

33. NUREG-1168, Chapter 1.

34. Tennessee's Final Comments, pp. 3–4.

35. Hoskins, Raymond E., "A Systems Evaluation of the High-Level Nuclear Waste Management System Based on Integration of Dual Purpose Cask Into The System As An Alternative to DOE's Proposed Monitored Retrievable Storage Facility As An Integral Part of The System," June 1989, pp. V–23-V–24.

36. When dual-purpose casks are used in European countries, the fuel is transported shortly after the cask is loaded. In the United States, the spent fuel would likely be stored at reactor sites in the dual-purpose cask for up to 20-30 years before being shipped. This extended storage prior to shipment is a cause of concern in the United States.

37. Department of Energy, "Monitored Retrievable Storage Submission to Congress," DOE/RW-0035/1-Rev. 1, Vol. II, Environmental Assessment for a Monitored Retrievable Storage Facility, February 1986 **(Hereafter cited as DOE/RW-0035/1-Rev. 1, Vol II).**

38. DOE/RW-0035/1-Rev. 1, Vol. II, Table 3, p. xviii.

39. DOE/RW-0035/1-Rev. 1, Vol II. p. xvi.

40. DOE/RW-0035/1-Rev. 1, Vol. II, p. xxi.

Chapter Five
Health and Safety Effects of Transporting Spent Fuel

The transportation of spent fuel is an issue of great concern to many people. That was evident from the testimony heard by the Commission around the country, and the Commission made it a high priority in its study. This chapter examines the effects of transporting spent fuel and compares the safety of transportation as it would be carried out in the spent fuel management alternatives under consideration.

Section One examines the radiological effects of transporting spent fuel with and without an MRS. Section Two examines the non-radiological risks with and without an MRS. Section Three shows the results of sensitivity analyses performed to make certain that differences in assumptions would not change the Commission's findings. Section Four presents the Commission's findings. Appendix J contains background information about the way spent fuel transportation is regulated and managed.

Section One: Radiological Effects

To compare the overall radiological effects of having and not having an MRS, the Commission estimated the total radiation exposure to all people during spent fuel transportation as it would be conducted for each alternative and then used a conversion formula to calculate how many deaths might result from each.

A. MRS and No-MRS Base Cases

The base cases in this chapter's analysis, using the computer model MARC (see Chapter Three, Section Two), are the same as the base cases—No-MRS, linked MRS, and unlinked MRS—outlined in Chapter Three, Section Three, and used in Chapter Four. The dual-purpose cask variation explained below in Part B uses a different set of assumptions.

To limit the number of cases considered to a reasonable number, a repository opening date of 2013 is assumed for all cases in this chapter. The repository start date only has marginal effect on the transportation risk. A few cases involving repository start dates other than 2013 also were considered. These, and the detailed modeling assumptions and computer output, are described in a report prepared by ICF Technology Incorporated for the MRS Review Commission.[1]

1. Total Radiological Dose

Table 5.1 shows the total amount of radiation exposure that would result from transportation if an MRS were part of the spent fuel management system and if it were not. The total amount of radiation exposure to all people during transport is expressed in person-rem, a measure of the effect of radiation on people. (Table 5.1 also contains the results of the dual-purpose cask variation discussed separately in Part B of this section.)

The "in-transit dose" is the dose that would be received by both the crew and the public during transport; the "handling dose" is the dose to workers during loading and unloading of casks onto and from transportation vehicles. "Total transport dose" is the sum of these two and is the total radiation dose that would be received by the workers and crew, and the general public along the paths of travel. This includes expected doses during normal transport and accidents. Estimated normal transport doses are significantly higher than estimated accident-related doses.[2] Table 5.1 shows that transportation of spent fuel, if there were not an MRS, results in a total dose of 12,200 person-rem. If there were a linked MRS, transportation of spent fuel would result in a total dose of 9,000 person-rem.

Table 5.1—Total Life-cycle Transportation Radiological Risk

Repository in 2013
(54% rail/46% truck from reactors; 100% rail from MRS)[f]

Cases	In-transit Dose[e]	Handling Dose[e]	Total Transport Dose[e]	Calculated Cancer Fatalities
No-MRS	7,900	4,300	12,200	4.9
No-MRS (dual-pupose casks; 100% rail from reactors)	210	4,100	4,300	1.7
Linked MRS (NWPAA)[a]	3,400	5,600	9,000	3.6
Unlinked MRS[b]	3,400	6,100	9,500	3.8
DOE No-MRS[c]	3,600	N.C.[g]	N.C.	N.C.
DOE MRS[c] Western Strategy[d]	2,100	N.C.	N.C.	N.C.

[a]MRS to begin operations in 2010
[b]MRS to begin operations in 2000
[c]DOE cases were presented in the Department of Energy's "MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility," May 1989, p. 25. The repository in DOE's system handled only 63,000 MTU. MARC systems handled 87,000 MTU. To provide a basis for comparison, these numbers were extrapolated from the actual DOE numbers.
[d]In DOE's western strategy, western reactors ship spent fuel directly to the repository rather than to the MRS.
[e]Dose in Person-rem
[f]Except for the No-MRS dual-purpose cask case, which assumes 100 percent rail transport from reactors.
[g]N.C. = Not Calculated

To calculate the number of fatalities that would result from such exposure, the Commission used the conversion formula used in Chapter Four. The formula is that for each 10,000 person-rem incurred, there would result 4 calculated latent cancer deaths. This means that transportation of spent fuel would result in about 5 calculated latent fatalities if there were no MRS and in less than 4 calculated fatalities if there were an MRS. These estimates are for the entire period during which the facilities would operate, or no more than one-tenth of one calculated latent cancer per year. The expected background radiation dose during the same time period would produce an estimated 120 cancer deaths per year to a population of a million people. The difference between the numbers with and without an MRS is far too small to be useful in deciding between the two alternatives.

Relative to the MRS alternative, the No-MRS alternative calls for a high proportion of truck use. This is because according to the DOE transportation system study assumptions,[3] adopted here for the base cases, many reactors do not have access to rail lines and would ship fuel all the way to a repository by truck if there were no MRS.[4] If there were an MRS, some fuel could travel to the MRS by truck and then be placed on a train to go to the repository.

To estimate the radiation exposure from transportation for each alternative, the Commission used the transportation radiation dose data contained in a modified version of

RADTRAN III, a new data base supplied by DOE, rather than the transportation dose data used in the DOE system study. The latter study used radiological dose data developed by Argonne National Laboratory. The RADTRAN data set produces higher estimates of truck doses and lower estimates of train doses than the Argonne data set does. The two data sets differ because of differences in assumptions about exposure. These are assumptions about such factors as the number and spatial distribution of people in rail yards, and the amount of shielding that may be provided by structures and vehicles.[5] Because the Commission used the RADTRAN III data, its dose estimates for the cases involving a large proportion of truck use are higher than they would have been if the Argonne dose data had been used. Similarly, the Commission's dose estimates for cases involving a large proportion of train use are lower than they would have been if the Argonne data had been used. The difference between the MRS and No-MRS dose is larger in the Commission's estimates than in DOE's system study estimates, but the differences are small in both sets of estimates. There are uncertainties associated with dose data sets and, therefore, with the calculated results.[6]

2. Surrogate Measures

In some of their studies on the transportation issue, DOE and the State of Tennessee use "surrogate measures" to approximate risk.[7] For example, to compare the relative radiological risk of various alternatives, these studies add up the "cask-days" (the total number of days a transport cask is in transit) or the "cask-miles" (the total number of miles casks travel). The assumption is that having more casks on the road would irradiate more people than getting all the fuel sent to its destination with fewer casks. "Shipment-miles" (the total number of miles to be traveled by all the shipments added together) is used as a surrogate for accident probability, since the probability of an accident varies directly with the total miles traveled, all other things being equal.

"All other things being equal" is an important caveat, and surrogate measures must be used with an awareness of their limitations. First, they represent only the in-transit portion of transport operations and do not portray all of the transport risks, which also include exposure to workers while handling the spent fuel. As Table 5.1 shows, handling risks are a significant element of total transport risk. Second, two shipment-mile numbers, representing two different alternatives with different transport mode mixes, are not comparable for considering non-radiological risks. Trucks and trains have very different traffic fatality rates; the fatality rate per train-mile is much higher than the corresponding rate per truck-mile. (Non-radiological risks for the different alternatives are discussed in Section Two, below.) Therefore, given two alternatives for interim spent fuel storage, each with a different mode split between truck and rail, a case with the lower total shipment-mile number, but higher number of train miles, may actually have more traffic fatalities and may not necessarily lower the overall transportation risk. As can be seen from the discussion in Section Two on non-radiological risks, traffic fatalities can be several times greater than projected cancer fatalities.

Table 5.2 shows the surrogate risk measures (shipment-miles and cask-miles) for the base cases portrayed in Table 5.1.

Table 5.2—Surrogate Life-cycle Transportation Risk Measures

Repository in 2013 (54% rail/46% truck from reactor; 100% rail from MRS)

Cases	Shipment-miles (in millions)	Cask-miles (in millions)
No-MRS	64.7	74.1
Linked MRS (NWPAA)[a]	26.9	40.3
Unlinked MRS (in 2000)	27.0	41.0

[a]MRS to begin operations in 2010

B. Dual-purpose Cask Variation

The two cases examined so far in this chapter assume that transportation of spent fuel would be by both truck and train to an MRS (or repository in the No-MRS case) and by train from the MRS to the repository. When DOE proposed an MRS in Tennessee, it asserted that having an MRS in the spent fuel management system would reduce transportation risks because an MRS could collect incoming small truck and rail shipments and combine them for transport to the repository in large rail casks shipped by dedicated trains (trains that would carry no cargo other than the spent fuel). The State of Tennessee challenged DOE's assumptions about transportation. Tennessee's position has evolved over time, and they now propose a No-MRS system in which spent fuel would be put into large casks that

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could be used for both storage and transport, called dual-purpose casks.[8] These casks would be shipped by rail directly from the reactors to the repository on dedicated trains. If a reactor did not have direct access to rail transport, the casks could be carried by barge or heavy-haul truck to the nearest railhead to be reloaded onto dedicated trains and sent to the repository. Tennessee argued that this method would reduce the total shipment-miles and cask-miles and thus reduce the overall radiological exposure during transportation. Tennessee also said that exposure to workers would be reduced because the casks require one less handling step, since dual-purpose casks would not necessitate returning the casks to the spent fuel pool to load fuel into transport casks.

The Commission analyzed a dual-purpose cask No-MRS case under assumptions favorable to the concept, including assumptions about maximum transportation efficiency. All reactors were assumed to have rail access and all transport from reactors was assumed to be by dedicated trains. These changes in assumptions lowered the total transportation dose estimate to 4,300 person-rem as shown in Table 5.1. Because of the all-rail assumption, the dual-purpose cask variation has the lowest radiological dose estimate of any of the cases examined, including those discussed in Section Three, below.

If a combination of standard storage and transport casks with the same capacity as the dual-purpose casks were used in the same all-rail transport case, the same dose estimates would result for transport to a repository, because the casks would travel the same number of cask-miles and be loaded and unloaded the same number of times. However, since standard storage casks would have to be returned to the spent fuel storage pool and the spent fuel transferred to a transportation cask, the radiological exposure at reactors for standard casks is higher.

However, overall doses for all the cases are small, and so are the differences among them, both in person-rem and the numbers of calculated latent fatalities they would produce. The small differences in the dose estimates do not provide a clear-cut rationale for choosing between the MRS and No-MRS alternatives, including the dual-purpose cask variation, on the basis of transportation radiological risks.

Also, the dual-purpose cask case analyzed assumed that the dual-purpose cask would be transportable even after long storage. Regulations might require the cask to be opened for testing (of the spent fuel basket, for example) before it is shipped after prolonged storage.[9] This would nullify the dual-purpose casks' theoretical advantage in reducing handling dose.

C. Findings

The Commission finds that the estimates of the radiological effects of transporting spent fuel are small, and the difference between the estimates for different alternatives is not large enough to make transportation effects significant in choosing between alternatives.

Section Two: Non-radiological Risks—Traffic Accidents

One of the consequences of transporting spent fuel would be an increase in the number of train and truck traffic accidents, simply because there would be more trains or trucks traveling. The radiological consequences of such accidents were taken into account in the analysis in Section One above; measures to prevent and manage the radiological consequences are discussed in detail in Appendix J. This section, Section Two, considers the non-radiological risks posed by spent fuel transportation, defined for the purposes of this study as the number of traffic fatalities that would result from train or truck accidents during the transport of spent fuel.

Overall, there is practically no difference between the results for the base cases—No-MRS, linked MRS, and unlinked MRS. About 16 traffic fatalities would result from transportation for each, during the entire time the MRS and/or the repository would operate (see Table 5.3). This is less than one fatality per year. Each year, 45,000 traffic deaths occur in the United States. These differences in traffic fatalities among the alternative strategies are not significant enough for them to factor in a decision on whether to build an MRS.

A. Traffic Fatality Rates

Truck accident statistics show the fatality rate for large combination tractor-trailer trucks is about 0.05 deaths per million vehicle-miles traveled.[10]

To determine the rail fatality rate, statisticians have used two different measures, one for miles traveled by entire trains and another for miles traveled by individual freight cars. The fatality rate for entire trains is about two deaths per million miles.[11] The rate for freight cars is much smaller. The freight-car rate is approximately 1/70 of the entire-train rate since trains average 70 freight cars each.

Consistent with the DOE transportation system study, spent fuel, when transported by rail, is shipped on "dedicated" trains,[12] that is, trains that carry nothing but spent fuel. These trains would carry three or five casks—three if leaving a reactor, five if leaving an MRS. This study uses the entire-train rate to estimate the fatality rate for these dedicated trains going to an MRS or repository, since the entire cargo is spent fuel. The collision of the train—not the number of railway cars involved—is the important component for calculating train accidents.

When empty casks are returned to reactor sites, they could be attached to non-dedicated trains. That is, the rail car carrying the empty cask would be part of a train with about 70 other cars carrying other kinds of cargo. Therefore, only one-seventieth of the accident would be attributed to empty cask transport. This study uses the freight-car rate to estimate the fatalities for these trips.

B. Base Cases and Dual-purpose Cask Variation

The non-radiological risks for the No-MRS and the MRS alternatives are presented in Table 5.3. The dual-purpose cask case, a variation of the No-MRS base case, was assumed to use 100 percent rail transport. The estimates of fatalities are for the entire period of the first repository program.

Table 5.3 provides an illustration of how little correlation there is between total shipment-miles (see Section One, above) and fatalities from traffic accidents for cases with very different mode splits. All three cases have nearly identical results for traffic fatalities—about 15—but very different shipment-miles. Fatality rates for trains are substantially higher than the rates for large combination tractor-trailer trucks; the difference in the fatality rates is so great that the substantially lower shipment-mile figure for the 100 percent rail case barely compensates. Indeed, in the 100 percent rail case, if the empty casks were modeled as being returned to the reactors via dedicated trains instead of conventional trains, the fatalities for the all-rail case would have been almost twice as high because of the additional train trips required.

C. Findings

The Commission finds that the non-radiological risks associated with the alternatives are small and that differences among them are insignificant in determining the need for an MRS.

Table 5.3—Life-cycle Non-radiological Risk

Repository in 2013

Cases	Traffic Fatalities	Shipment-miles (in millions)
No-MRS (54% rail/46% truck)	15.5	64.7
No-MRS (Dual-purpose Casks; 100% rail)	15.5	7.8
Linked MRS[a] (NWPAA; 54% rail/46% truck from reactors; 100% rail from MRS)	15.3	26.9

[a]MRS to begin operations in 2010

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Section Three: Sensitivity Analyses of Radiological and Non-radiological Factors

To see how changes in certain assumptions would affect the results of the base case analyses, the Commission conducted "sensitivity analyses," as explained in Chapter Three. It examined the effects of linkages, transshipments among reactors, increased rail use from reactors, routing to avoid population centers, changing the theoretical location of the MRS, and rod consolidation at reactors. These factors have both radiological and non-radiological implications.

A. Linkages

Provisions in the Nuclear Waste Policy Amendments Act (NWPAA) link the schedule for developing an MRS to progress on developing the repository. The linkages restrict the MRS schedule so that the MRS could begin operating no earlier than three years before the repository begins operating. The linkages also limit the MRS's capacity to 10,000 MTU before the repository's opening and 15,000 MTU thereafter.

Table 5.4 shows the effects of these schedule linkages and capacity constraints—separately and combined—on transportation risks. They show the changes in estimated radiological dose and non-radiological (traffic accident) fatalities.

Table 5.4 shows that linkages have little effect on transportation risk, either radiological or non-radiological. The estimated doses vary in range from a low of 9,000 person-rem to a high of 9,500—a change of less than 8 percent. The traffic fatality differences are even smaller. Life-cycle traffic fatality estimates range from 15.3 to 15.9—a change of less than 5 percent. The differences are small because in all cases all spent fuel must ultimately be moved to the repository.

B. Intrautility Transshipment

Intrautility transshipment was analyzed for its effects on system safety performance. The effects on transportation risks were estimated to be small. (See Table 5.5.)

In the No-MRS case, transshipment would provide an opportunity for reactors with truck access only to ship to

Table 5.4—Effects of Linkages on Life-cycle Transportation Risk

Repository in 2013
(54% rail/46% truck from reactors; 100% rail from MRS)

Cases	Total Transport Dose (person-rem)	Calculated Cancer Fatalities	Traffic Fatalities
Linked MRS (NWPAA)[a]	9,000	3.6	15.3
Unlinked MRS[b]	9,500	3.8	15.9
MRS (NWPAA schedule linkages; no capacity limit)[a]	9,200	3.7	15.3
MRS (15,000 MTU capacity limit; no schedule linkages)[b]	9,100	3.6	15.6

[a]MRS to begin operations in 2010
[b]MRS to begin operations in 2000

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reactor sites (owned by the same utility) having rail access and take advantage of the greater transportation efficiency for the eventual trips to the repository. In this case, transshipment would reduce total truck miles and increase rail miles slightly. The effect is to reduce dose and increase traffic fatalities very slightly. With an MRS in the system, transshipment plays a lesser role with respect to transport efficiency resulting in smaller differences in doses.

C. Increased Rail Transport from Reactors

Most cases analyzed in this chapter follow the assumptions in the DOE transportation system study about use of rail service from reactor sites: 54 percent of the sites have rail access, and for those which ship by rail, fuel is shipped in three-cask dedicated trains.

Assumptions about both the mode mix (proportion of trains and trucks) and the number of casks per train can be varied. Section One, Part B analyzed the dose in a case in which all reactors were assumed to have ready access to rail service and all spent fuel was transported 100 percent by rail. Even in this extreme case, the decrease in transport radiological risk was small: the dose changed from 12,200 person-rem for the No-MRS case to 4,300 person-rem for the 100 percent rail case with dual-purpose casks (Table 5.1). Section Two showed that traffic fatalities remained virtually the same despite variations in mode mix.[13]

D. Population Avoidance Routing

It has been proposed that transportation routes be chosen to avoid population centers to minimize the number of people exposed.[14] Avoiding population centers of certain sizes (for example, 500,000 or greater) would not necessarily minimize the total number of people exposed along the entire route. A direct route near or through some large population centers might actually expose fewer people during the whole trip than a longer, more circuitous route avoiding those centers; for example, the longer trip could, to avoid one center of 500,000 people, go through three centers of 400,000 people each.

The routing rationale used in this study is the Department of Transportation's (DOT) highway routing rule for trucks and an analogous one for rail. There is no Federal

Table 5.5—Effects of Transshipment on Life-cycle Transportation Risk

Repository in 2013
(54% rail/46% truck from reactors; 100% rail from MRS)

Cases	Total Transport Dose (person-rem)	Calculated Cancer Fatalities	Traffic Fatalities
No-MRS	12,200	4.9	15.5
No-MRS Transshipment	12,000	4.8	15.6
MRS 2010[a]	9,200	3.7	15.3
MRS 2010[a] Transshipment	9,300	3.7	15.4
MRS 2000[b]	9,500	3.8	15.9
MRS 2000[b] Transshipment	9,600	3.8	16.0

[a]NWPAA schedule linkages; no capacity limits
[b]Unlinked (No schedule linkages; no capacity limits)

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routing standard for rail (see Appendix J). The DOT high way routing standards do not require that trucks avoid population centers. They only require that trucks use the Interstate System bypass or beltway when available.[15] The Commission defers to DOT's expertise in highway routing.

To test the population-avoidance concept for rail, the Commission developed a No-MRS, 100 percent rail case which avoids population centers of 500,000 people or more. The result is that travel would increase from the 7.8 million train-miles of the previous 100 percent rail case to 9.1 million train-miles. Radiation dose estimates would remain virtually unchanged at 4,300 person-rem; however, estimated traffic fatalities would increase from 15.5 to 18.2. Therefore, this variation does not appear to reduce the already low transportation risks, and may slightly increase them.

E. MRS Location

Recommending a site for an MRS is outside the Commission's charge. For analytical purposes, the MRS was assumed to be located at a theoretical (generic) site in the Eastern United States identified by an averaging method described in Appendix G. To test the effects of the MRS location on transportation risks, the location of the MRS was changed to a generic central U.S. site. The results show little change in risk as a result of a change in MRS location (see Table 5.6).

The slight increase in radiological risk for the central MRS case is attributable to an increase in truck shipment-miles: from 16 million to 25 million. The slight decrease in traffic fatality estimates is due principally to a reduction in the miles traveled from the MRS, since a centrally-located MRS would be closer to the proposed western-located repository than an eastern-located MRS would be. In the extreme case, if the MRS were located at the repository site, the transportation risk would be the same as the No-MRS case, since all spent fuel must move from the reactors to the repository site in both cases.

F. At-reactor Rod Consolidation

If spent fuel rods are consolidated at a reactor, the reactor's spent fuel pool can store a greater quantity of spent fuel. Hence, at-reactor rod consolidation is an alternative to dry storage to increase interim storage capacity at some reactors. To test how using rod consolidation might affect transportation risks, the Commission analyzed a No-MRS, at-reactor consolidation case. About 50 percent of the reactors would have the capability to consolidate.[16] This case assumed that these reactors would consolidate fuel to the end of their operating lives. Truck cask capacity (3PWR/7BWR assemblies) was not increased to take advantage of the reduced volume of the consolidated assemblies because the 80,000-pound gross vehicle weight legal limit for trucks would be exceeded. That is, the case of using overweight trucks—with its permitting and other institutional issues—was not modeled. (For a discussion of overweight truck issues, see Appendix J.) Rail cask capacity was, in effect, doubled. Since rail shipments contribute little to radiological dose, consolidation had limited effect on overall transportation dose (Table 5.7). Reduction of the

Table 5.6—Effects of MRS Location on Life-cycle Transportation Risk

Repository in 2013; MRS in 2000[a]
(54% rail/46% truck from reactors; 100% rail from MRS)

Cases	Total Transport Dose (person-rem)	Calculated Cancer Fatalities	Traffic Fatalities
Eastern MRS	9,500	3.8	15.9
Central MRS	10,500	4.2	15.1

[a]Unlinked (No schedule linkages; no capacity limits)

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number of rail shipments needed, however, lowered the traffic fatality estimate from over 15 to under 11.

G. Findings

The Commission finds that estimates of transport risks would remain low in all variations on the base cases, and the differences among the realistic options are small. These differences should play no discriminating role in determining the need for an MRS. The theoretical 100 percent rail No-MRS case had the lowest transport dose estimate, partly because the model's unit dose rates are much lower for rail than truck.

Table 5.7—Effects of At-reactor Rod Consolidation on Life-cycle Transportation Risk

Repository in 2013; No-MRS (54% rail/46% truck from reactors)

Cases	Total Transport Dose (person-rem)	Calculated Cancer Fatalities	Traffic Fatalities
No Consolidation	12,200	4.9	15.5
Consolidation at 50% of reactors	10,800	4.3	10.8

Section Four: Findings

The Commission finds that transportation risks—both radiological and non-radiological—associated with all of the spent fuel management alternatives are small and are not discriminating in the determination of the need for an MRS. Further, because the risks are small, apparent differences in results arising from the use of different assumptions, whether they pertain to transportation mode split or the role of special casks, are equally non-discriminating in the decision-making.

This finding is in accord with the results of other studies, although the numbers may differ. Before undertaking these analyses, the Commission conducted a review and critique of transportation and siting-related studies by the Department of Energy and the State of Tennessee, directly addressing the need for an MRS.[17] These studies also found that transportation risks are small. Indeed, the Commission agrees with both the current position of DOE[18] and the conclusion of the University of Tennessee[19] that these small risks should not be a discriminating factor in determining the need for an MRS.

Chapter Five Notes

1. ICF Technology Inc., "Transportation Impacts of the Federal Waste Management System," October 1989 **(Hereafter cited as ICF, Transportation Impacts)**.

2. For example, for the No-MRS case in Table 5.1, of the 7,900 person-rem in-transit dose in the No-MRS case, only 70 person-rem are attributable to accidents.

3. Office of Transportation Systems and Planning, Battelle Nuclear Systems Group, "MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility," May 1989 **(Hereafter cited as Task F)**, p. 15.

4. Only 56 percent of the reactors are assumed to have rail access.

5. McSweeney, T.I., Office of Transportation Systems and Planning, Battelle Nuclear Systems Group, personal communication Sherwood C. Chu, MRS Review Commission staff, August 24, 1989.

6. ICF, Transportation Impacts, Section 7.0.

7. ICF Technology Incorporated, "Historical MRS Siting and Transportation Studies: A Review and Analysis," June 1989 **(Hereafter cited as ICF, Historical Transportation Studies)**.

8. Hoskins, Raymond E., "A Systems Evaluation of the High-Level Nuclear Waste Management System Based on Integration of Dual Purpose Cask into the System as an Alternative to DOE's Proposed Monitored Retrievable Storage Facility as Integral Part of the System," June 30, 1989.

9. It is NRC's practice to recertify transport casks at five-year intervals.

10. Department of Transportation, Federal Highway Administration, John Grimm, Director, Office of Motor Carrier Information Management And Analysis, personal communication Sherwood C. Chu, MRS Review Commission staff, June 5, 1989.

11. Department of Transportation, Federal Railroad Administration, "Accident/Incident Bulletin No. 156," July 1988, pp. 5, 16.

12. Task F, p. 18.

13. Radiological risk would not be affected by increasing the number of casks per train since dose is calculated on a per cask basis. Only non-radiological risk would be affected because there will be fewer train-miles traveled from the reactors. If five casks were shipped per train from reactors instead of three, each million train-miles of three-cask trains traveled would be reduced to 600,000 train-miles. The fatality rate for trains is about two per million train-miles, so the fatality rate would be lowered by 0.8 of one fatality. For the cases studied, rail travel ranged from 2.3 to 7.8 million miles in three-cask trains. If five-cask trains were used throughout, the reduction in estimated traffic accident fatalities for the cases analyzed would be in the range of 1.8 to 6.2 fatalities for the life-cycle of the whole shipping campaign.

14. Hamilton, William, Manager, Nuclear Waste Department, Westinghouse Electric Corporation, Transcript of Monitored Retrievable Storage Review Commission Public Hearings **(Hereafter cited as Hearings Transcript)**, December 1, 1988, p. 45; Massaro, Tony, Director of Environmental Affairs, City and County of Denver, Colorado, Hearings Transcript, January 5, 1989, p. 18.

15. 49 CFR 177.825(b).

16. Ebasco, "Spent Fuel Storage Need and At-Reactor Capability Study," June 1989, Table 3.3.

17. ICF, Historical Transportation Studies.

18. Isaacs, Thomas H., Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE Position on the Monitored Retrievable Storage (MRS) Facility," Prepared Remarks Before the Monitored Retrievable Storage Review Commission, May 25, 1989, pp. 19–21.

19. University of Tennessee, Transportation Center, "Monitored Retrievable Storage of Spent Nuclear Fuel: Transportation Studies," December 16, 1985, revised October 20, 1986, p. 48.

Chapter Six
Spent Fuel Management Costs

This chapter analyzes the costs that would be incurred by the Department of Energy (DOE) and utilities that operate nuclear power plants if a monitored retrievable storage (MRS) facility were or were not part of the U.S. spent fuel management system. Section One explains the costs and defines terms used in this analysis. Section Two explains what data sources the analyses used and what differences in results are created by using one rather than another data source. Section Three analyzes the costs of the various spent fuel management alternatives examined by the MRS Review Commission and shows how the costs change with time. Section Four explains the effects of discounting. Section Five contains the Commission's findings.

Section One: Background

The costs this chapter discusses are those of managing all the spent fuel that has been or will be produced at existing U.S. nuclear power plants, from the time the fuel is discharged from the reactor to when it is emplaced in a repository. The study assumes that no more nuclear plants will be built in the United States. The basic unit of analysis is the "life-cycle cost" of the entire national spent fuel management and disposal system. It is called life-cycle because it refers to the entire time the spent fuel management program operates.

Estimates of the time period required to emplace all the spent fuel in permanent geologic disposal vary somewhat with assumptions about how long existing reactors will operate, whether reactors' operating lives will be extended, whether reactors will shut down early, when reactors still under construction will become operational, and what system—MRS or not—is used to manage the spent fuel. However, this chapter's analyses assume that the last removal of spent fuel from an operating reactor core in the United States will take place in the year 2037 and that all spent fuel will have been emplaced in the repository by the year 2050 at the latest.

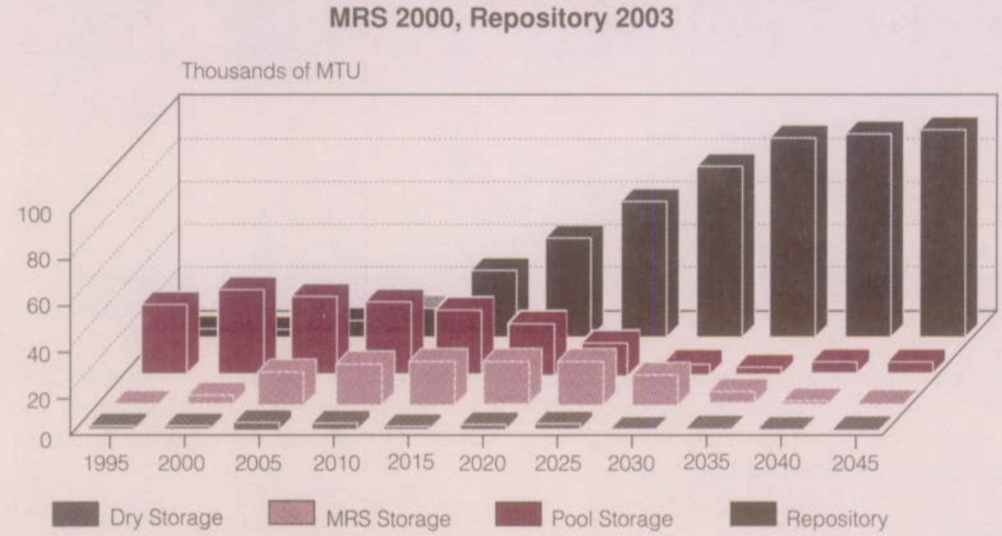
Figure 6.1 and Table 6.1 illustrate where spent fuel would be stored from 1995 through 2045 if there were a linked MRS in the system in 2000 and a repository in 2003. Figure 6.2 and Table 6.2 illustrate where the same amount of fuel would be stored if there were no MRS and if a repository were delayed until the year 2013. Each figure shows how much fuel would be stored where in a given year. For example, Figure 6.1 shows that in the year 2015, if there were a linked MRS, a relatively small amount of fuel, only about 400 metric tons uranium (MTU), would be in dry storage at reactors, about 28,000 MTU in pool storage, 15,000 MTU in MRS storage, and about 28,000 MTU at the repository. For the same year, Figure 6.2 shows that, if there were no MRS, slightly more than 20,000 MTU would be in dry storage, almost 50,000 MTU in pool storage, and only 2,000 MTU at the repository.

The cases these figures illustrate are two of the six principal cases analyzed in this chapter. The purpose of the analysis is to estimate how and why spent fuel storage and transportation costs will vary over time as the location of the spent fuel changes. As the two figures illustrate, the variation between scenarios can be quite large even though the total amount of spent fuel to be stored, transported, and disposed of remains the same.

Some costs would be paid by the utilities directly and some by the Nuclear Waste Fund (NWF). The proportion each would pay also varies considerably among the cases this chapter analyzed.

Under current law, utilities pay the costs of managing and storing spent fuel while it is stored at reactors. The cost of storing spent fuel at reactors includes the cost of reracking pools to increase their capacity and providing out-of-

Figure 6.1—Location of Spent Fuel, MRS in 2000. Repository in 2003[a,b]



[a]Source: WACUM Simulator Model
[b]Data given in Table 6.1.

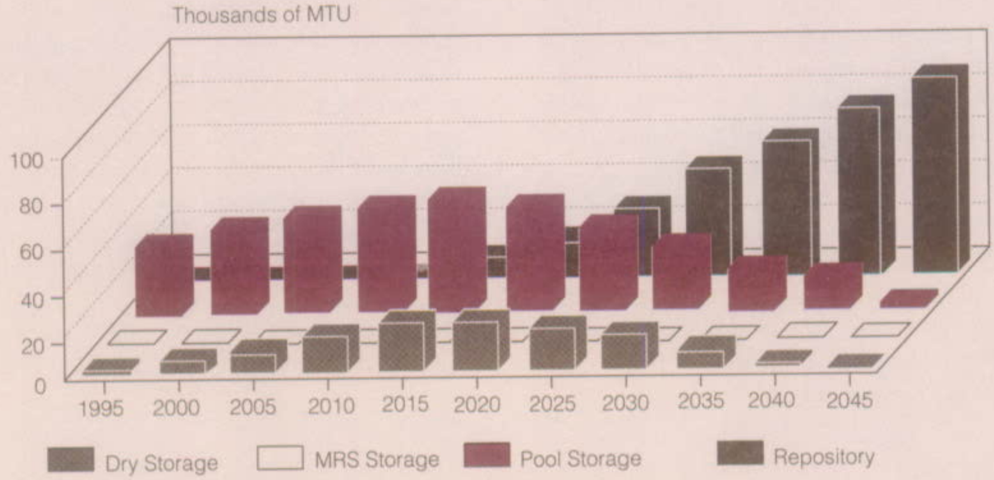
Table 6.1—Location of Spent Fuel, MRS in 2000, Repository in 2003[a,b]

YEAR	DRY STORAGE AT-REACTORS	MRS STORAGE	POOL STORAGE AT-REACTORS	REPOSITORY
1995	1,286	0	29,860	0
2000	3,194	2,000	36,125	0
2005	3,562	12,099	33,273	2,000
2010	2,351	15,000	30,157	12,787
2015	422	15,000	27,862	27,786
2020	174	15,000	19,516	42,785
2025	201	15,000	10,737	57,784
2030	0	9,768	3,592	72,784
2035	0	2,308	543	83,783
2040	0	0	148	86,607
2045	0	0	0	86,756

[a]Source: WACUM Simulator.
[b]Shown graphically in Figure 6.1.

Figure 6.2—Location of Spent Fuel, No-MRS. Repository in 2013[a,b]

No–MRS, Repository in 2013



One 87,000 MTU repository

[a]Source: WACUM Simulator Model

[b]Data given in Table 6.2.

Table 6.2—Location of Spent Fuel, No-MRS, Repository in 2013[a, b]

YEAR	DRY STORAGE AT-REACTORS	MRS STORAGE	POOL STORAGE AT-REACTORS	REPOSITORY
1995	1,286	—	28,680	0
2000	3,711	—	36,807	0
2005	8,019	—	42,026	0
2010	13,932	—	46,362	0
2015	20,007	—	49,914	1,149
2020	20,819	—	43,857	12,798
2025	19,208	—	36,799	27,715
2030	15,459	—	28,037	45,644
2035	8,311	—	20,438	57,596
2040	1,048	—	13,272	72,436
2045	0	—	0	86,756

[a]Source: WACUM Simulator.

[b]Shown graphically in Figure 6.2.

pool dry storage if necessary. If a repository or an MRS were not operating or did not have adequate capacity, spent fuel stored at shutdown reactors would have to remain there. In this case, the utility would incur considerably more expense for spent fuel management and security than if the spent fuel could be removed and responsibility for it turned over to the Department of Energy. DOE analyses do not include these costs as a component of at-reactor costs, but the Commission believes these costs are a legitimate component of total system cost and should be considered in evaluating the need for an MRS facility.

After spent fuel leaves the reactor site, costs are to be paid from the federally administered Nuclear Waste Fund (NWF). The NWF pays the costs of: transporting spent fuel from reactors to the repository and, if it exists, the MRS; building and operating the repository and MRS; funding all of DOE's research and development to support the design of the national nuclear waste management and disposal system; benefit payments to State governments or Indian Tribes; and the department's expenses to administer the national nuclear waste program.

Utilities are required to pay into the NWF one mill per net kilowatt-hour of electricity they generate from nuclear sources. This fee is treated as an operating expense and passed on to consumers through the utilities' rates. At-reactor storage costs incurred directly by utilities are also passed on to ratepayers, but some utilities may have to pay considerably more than others for this storage. For example, a utility operating a new reactor with a large pool might incur little extra expense if the repository were delayed and an MRS were not available, as in the case illustrated in Figure 6.2, while a utility operating an older reactor with a smaller pool might have to add substantial amounts of dry storage in the same circumstances. The distribution of system costs is discussed in Chapter Seven.

Section Two: Cost Estimate Data Sources and Differences

The cost analyses in this chapter are based on several data bases. Each data base has its uses and limitations. This section explains the data sources, then explains the differences among them.

A. Data Sources

The primary data sources for this chapter are DOE's **T**otal-**S**ystem **L**ife-**C**ycle **C**ost (TSLCC)[1] and a data base and a model developed for the Commission—the **I**nterim **S**pent **F**uel **M**anagement Cost Data Base (ISFM) and The Nuclear **WA**ste **C**ost Data Base and Sim**U**lation **M**odel (WACUM).

1. DOE Cost Analyses

a. TSLCC

Annually since 1983, the Department of Energy has estimated the national nuclear waste management and disposal system's life-cycle costs and has reported them in the *Total-System Life-Cycle Cost Report* (TSLCC). DOE's purpose in doing so is to determine whether or not the fee levied on nuclear-generated electricity and paid into the NWF will produce enough revenue to pay for the projected costs of the system over its lifetime. Table 6.3 lists the estimates made each year in this Total-System Life-Cycle Cost Report.

The estimates change from year to year because of changes in: (1) the configuration and components of the system being costed, (2) assumptions about when system components would become operational, and (3) assumptions about how much waste would be created. There have been significant changes in each assumption since 1983.[2]

The 1983–1987 estimates in Table 6.3 are given in ranges, because, before the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), DOE was estimating costs for characterizing three sites for the first repository. Thus, the total cost varied according to which of three repository sites was used, and DOE provided a range to reflect that fact. The single value shown for 1988 reflects the fact that the NWPAA directed DOE to characterize only the Yucca Mountain site.

In the system studies[3] (see below), prepared by DOE for the Commission, and in the 1989 TSLCC report, DOE discussed two major modifications to previous system designs, both of which have major cost implications. The first is the substitution of a "basic" MRS, which would limit its services essentially to storing intact spent fuel, in place of the earlier proposal for a "fully integrated" MRS, which would have consolidated and packaged spent fuel. In a two-repository system, such as the one the Nuclear Waste Policy Act of 1982 envisioned, the MRS would service only the first repository, with the second repository receiving spent fuel directly from the reactors. DOE believes that building a basic, rather than integrated, MRS would reduce an MRS facility's estimated cost from \$3.1 billion to \$1.8 billion for a one-repository system and from \$2.3 billion to

Table 6.3—Comparison of Historical Total-system Life-cycle Cost Estimates[a,b]

Year of Estimate	Range of Estimate in Billions of Current Dollars[c]	Range of Estimate in Billions of Constant 1988 Dollars
1983	19.3 to 19.8	23.7 to 24.3
1984	20.9 to 24.4	24.7 to 28.8
1985	23.8 to 29.7	27.1 to 33.8
1986	26.2 to 34.0	28.9 to 37.4
1987	32.1 to 38.2	34.5 to 41.0
1988[d]	32.0	32.0

[a]Source: Department of Energy, "Analysis of the Total-System Life-Cycle Cost for the Civilian Radioactive Waste Management Program," DOE/RW-0236, May 1989, p. 1-11.

[b]Includes only cost paid by the Federal government from the Nuclear Waste Fund; utilities' cost for at-reactor storage are not included.

[c]Current dollars are the "dollars" of the year prior to the year of the estimate, i.e.,the 1983 estimate reflects prices prevailing in 1982, etc. except for 1988 which uses 1988 dollars because the report was not issued until 1989.

[d]The 1988 estimate was made for a system including a packaging MRS and two repositories.The range in the previous years was the result of a range for development and evaluation (D&E) and repository costs reflecting the characterization of three repositories in different geologic media. The 1988 estimate reflects the Nuclear Waste Policy Amendment Act (NWPAA) directing DOE to characterize only one repository at Yucca Mountain.

$1.4 billion in the two-repository case.[4] The second major change reflected in the 1989 TSLCC report involves building one repository rather than two. DOE estimates that this change would reduce the estimated total system cost by $7.3 billion.[5] The 1989 estimate in Table 6.3 is based on a two-repository, "packaging" MRS to be comparable with earlier years' estimates. If a basic MRS with only one repository were used instead, the total system cost would drop to $23.8 billion.[6] In this analysis, the Commission used the basic MRS and a one-repository system as the basis for comparing alternatives.

Although detailed in design and well documented and rigorous in its analysis, the TSLCC report was of limited use in analyzing the economic aspects of the charge that Congress gave to the MRS Review Commission. The TSLCC report's focus is largely limited to DOE's current program strategy, which does not include the No-MRS alternative. The Commission was required to evaluate DOE's strategy as well as the principal alternatives to it, specifically the No-MRS alternative. Further, the TSLCC Report rests on "a single set of engineering assumptions" and thus does not provide an adequate basis for analyzing the uncertainty in the cost estimates evident in the year-to-year variations observable in Table 6.3.[7]

b. System Studies

DOE's system studies include a wider range of alternatives. The studies were based on some 90 different cases, corresponding to different system configurations and schedules, but all of the cases were based on the same set of engineering cost estimates. Hence, DOE's analysis of the uncertainty inherent in the cost estimates is limited; moreover, DOE did not consider delays in the repository program beyond the year 2013.

2. Commission Analytical Tools

Because of the DOE studies' limitations and the record of significant increases in the estimates of the total program costs, the Commission conducted an independent survey of existing cost estimates and developed its own analytical tools, a data base and a simulation model, to analyze their uncertainty.

a. The Interim Spent Fuel Management Cost Data Base (ISFM)

The ISFM has two parts: (1) a historical data base which summarizes previous cost estimates and (2) a probabilistic data base that was derived from a panel of experts who reviewed the historical data base and estimated a probability distribution for each principal cost in a subjective but structured manner.[8]

The costs were organized into 90 "accounts" defined so they could be used as input data in the WACUM cost simulation model described below. An account can be understood as a discrete cost-incurring activity in the spent fuel management system, such as reracking pools, unloading casks, or making benefit payments to States or Indian Tribes.

To define the probabilistic data base, the experts met as a group. After being trained in probabilistic cost estimation, the group developed a probability distribution for each of the 90 cost accounts in the probabilistic version of the ISFM cost data base.[9] Although the group used the historical estimates that had been made by DOE and others as a point of departure, their goal was to forecast a range for the degree of uncertainty in these costs for each account. The principal reasons for uncertainty are that the technology is still being developed; the estimates have to extend 40 or 50 years into the future; the regulations are still evolving; and legislation may change.

b. The Nuclear WAste Cost Data Base and SimUlation Model (WACUM)

WACUM was developed to estimate the spent fuel management and disposal system's costs under a variety of possible cases. It was designed to use the ISFM cost accounts to analyze the uncertainty associated with the costs of various system elements, including the MRS construction and operation.[10] WACUM constructs a "requirements file" that indicates how large or small various system parts would have to be—for example, MRS capacity, how many casks are needed for at-reactor storage, and for how long the facilities in the system will have to operate. Then the model combines the requirements file with the data base to estimate the total system cost for different assumptions about what the composition of the system would be, e.g., whether it would include an MRS and when the repository would begin to operate. WACUM allows the user to choose among three pick-up rules: oldest fuel first (OFF), which was used in the DOE studies;[11] oldest fuel first from storage pools which are full (FUL), and oldest fuel first from pools which are full and have been reracked (RRK).[12]

The MRS Review Commission's Analysis of System Risk and Cost (MARC) network optimization model (described in Chapter Three) also can be used to analyze costs and has been used to analyze various alternatives. The analysis in this chapter relies primarily on the WACUM model and the ISFM data base, but the relationship between the costs of the cases analyzed is the same whether the WACUM or MARC costs are used.

B. Data Differences

Table 6.4 compares cost estimates prepared for the Commission by DOE to the Commission's WACUM estimates.[13] With two exceptions, DOE's estimates use the same cost assumptions and estimating methods as the DOE system studies and TSLCC report. They assume a single repository and the same repository and MRS schedules used in the Commission's cases. Total costs and component costs (parts of the total cost, such as at-reactor costs) for three cases and three schedules are shown.

The apparent correlation between the total cost estimates suggests more similarity between the DOE and WACUM estimates than a comparison of the individual cost components justifies. Significant differences between the two estimates are the result of differences among the types of costs included, the basic assumptions used, and the estimation methods used.

1. Assumptions and Inclusions

a. Totals

DOE included in its estimates the costs of processing high-level defense wastes as well as civilian wastes; WACUM estimated only civilian waste costs. If defense wastes had been included, the WACUM totals would be about 10 percent higher.[14]

b. At-reactor Storage Costs

Another major source of difference between the estimates is apparent in the treatment of at-reactor storage costs. The costs of acquiring and servicing dry storage facilities comprise most of DOE's estimated at-reactor storage costs, while WACUM includes a considerably wider range of costs in this category. The WACUM estimates include the costs of reracking pools, loading and unloading casks, and all necessary at-reactor infrastructure, as well as, most important, the costs incurred by delaying the removal of spent fuel from shutdown reactors. DOE discusses the costs of delaying the removal of spent fuel from shutdown reactors in the Task G Report of the system studies, but does not incorporate them into its estimates of total system costs.[15]

As illustrated in Table 6.4, which shows the costs of delaying the removal of spent fuel from shutdown reactors in brackets under total at-reactor costs,[16] the shutdown reactor costs become substantial in cases in which the reposi-

Table 6.4—Comparison of WACUM and DOE Total-system Life-cycle Cost Estimates[a] (Billions of Constant 1989 Dollars)[b]

YEAR REPOSITORY STARTS	NO-MRS		LINKED MRS[c]		UNLINKED MRS[d]	
	WACUM	DOE	WACUM	DOE	WACUM	DOE
2003						
TOTAL	24.8	23.0	26.9	25.2	27.0	25.2[e]
At-Reactor	2.3	0.9	1.2	0.4	0.9	0.4
[Shutdown Reactors][f]	[1.2]	NI[i]	[0.5]	NI	[0.2]	NI
Development & Evaluation	9.0	9.7	9.8	10.1	9.8	10.1
Transportation	3.7	2.4	3.7	2.7	3.8	2.7
Repository[g]	9.7	9.6	9.7	9.4	9.7	9.4
MRS	—	—	2.5	1.9	2.8	1.9
Benefits[h]	—	0.5	—	0.7	—	0.7
2013						
TOTAL	26.6	25.7	27.9	27.8	26.7	27.4
At-Reactor	5.1	2.0	3.7	1.5	1.1	0.4
[Shutdown Reactors][f]	[2.7]	NI	[1.3]	NI	[0.3]	NI
Development & Evaluation	9.0	11.8	9.7	12.3	9.8	12.0
Transportation	3.3	2.3	3.3	2.5	3.3	2.7
Repository[g]	9.2	9.2	9.2	9.1	9.2	9.1
MRS	—	—	2.1	1.7	3.2	2.4
Benefits[h]	—	0.5	—	0.7	—	0.7
2023						
TOTAL	28.0	27.9	29.5	30.1	27.2	30.0
At-Reactor	6.6	2.3	5.9	2.3	1.4	0.4
[Shutdown Reactors][f]	[3.6]	NI	[3.0]	NI	[0.5]	NI
Development & Evaluation	9.0	13.7	9.6	14.3	9.9	13.8
Transportation	2.9	2.3	2.9	2.6	2.8	2.8
Repository[g]	9.4	9.2	9.4	9.1	9.4	9.1
MRS	—	—	1.7	1.7	3.7	3.1
Benefits[h]	—	0.4	—	0.6	—	0.7

[a]Estimates were supplied by DOE at the Commission's request for these cases. WACUM estimates were made with the WACUM cost simulator. See Appendix G for acceptance schedules.

[b]DOE estimates were made in 1988 dollars. They were converted to 1989 dollars by means of the implicit GNP price deflator, as explained in Note 13, Chapter 6.

[c]MRS is assumed to open three years before the repository and is subject to a 15,000 MTU capacity limit per NWPAA.

[d]MRS is assumed to begin operating in the year 2000, without a capacity limit.

[e]DOE's estimates for the unlinked MRS in 2000 are the same as those for the linked MRS.

[f]Cost of delaying the removal of spent fuel from shutdown reactors, included in at-reactor components.

[g]Both estimates based on a single repository. WACUM assumes an efficient (RRK) pick-up rule is used, in which fuel is picked up first from reactors that are full and have been reracked, then from full reactors and then reverts to the oldest fuel first rule. DOE assumes the oldest fuel first pick-up rule.

[h]Included in the repository and/or MRS account in the WACUM estimates.

[i]NI indicates not included.

7 0 2 3 0 2 1 0 9

tory is significantly delayed and an MRS with sufficient capacity to accept the fuel is not available. In the extreme case, in which the repository does not open until the year 2023, the shutdown reactor costs would add $3.6 billion to the total system costs of a No-MRS case but would amount to only $0.5 billion if an unlinked MRS had been operating since 2000. If these costs were not included in the Commission's estimates of at-reactor storage costs, the estimate would come much closer to DOE's, but the difference between the total system cost estimates, in most cases, would grow rather than shrink.[17] Shutdown reactor costs are included in the WACUM estimates but not in those made by DOE. As the repository is delayed, this difference is the principal reason why the No-MRS alternative becomes more expensive than the unlinked MRS case in the WACUM estimates, but remains less expensive in the DOE estimates.

The differences between at-reactor storage estimates also are partly attributable to the different pick-up rules. DOE used the oldest fuel first pick-up rule, and WACUM used the more economically efficient RRK pick-up rule described in Section Two, Part A.2, above. The oldest-fuel-first pick-up rule is inefficient because older fuel may be picked up from reactors with in-pool storage capacity before fuel can be picked up from reactors with full pools which must put spent fuel in dry storage. Thus, more expense is incurred for dry storage than an efficient pick-up rule would incur. Using a more economically efficient pick-up rule reduces at-reactor storage cost about ten percent, but this reduction translates into a much smaller reduction in total system costs since this cost category comprises a relatively small part of the total.

c. Development and Evaluation Costs

Development and evaluation (D&E) costs are also a significant source of difference in Table 6.4 in the delayed repository cases. The panel of analysts which created the ISFM data base for the WACUM model did not attempt to establish a probability distribution for these costs. The information available at the time reflected the parallel characterization mandate calling for DOE to ascertain the suitability of three repository sites simultaneously, rather than making the sequential characterization mandated by the NWPAA, which directed DOE to characterize only the Yucca Mountain, Nevada site. Since most costs in this category are related to the repository, the panel did not believe it had adequate information to establish a meaningful probability distribution for D&E costs. Hence, in the WACUM model, D&E costs are held essentially constant at the level of the DOE estimate for the repository in the year 2003 case. D&E costs for the MRS and the transportation system are included or excluded as appropriate for the case being analyzed.

DOE assumes that D&E costs will continue to accumulate if the repository is delayed and, when the delay is considerable, this creates a significant difference between the two estimates. If the D&E costs in the WACUM estimates were to be escalated at the same rate observed in the DOE estimates for the cases in which the repository is assumed to be delayed, the WACUM total cost estimate would increase by approximately 15 percent.[18]

2. Treatment of Uncertainty

The WACUM estimates, described in Section Two, Part A.2.b, were made with the probabilistic or encoded version of the ISFM cost data base. DOE's estimates usually include a 20 to 40 percent contingency, but they are based on today's best engineering judgment of what it would cost to build or operate the cost component in question.

Since the WACUM estimates explicitly focus on uncertainty in cost and since the uncertainty involved in some system elements is so great, the WACUM estimates tend to be higher than the DOE estimates for many of the system's individual cost accounts. For example, the repository cost component in Table 6.4 is derived from ISFM data for several accounts, a major one being the cost of the waste package. WACUM's "expected" or average value of the probability distribution, derived from the ISFM data base, for the cost of an individual disposal waste package is $73,000. This is more than twice as high as the DOE's $31,000 estimate. However, the modal, or "most likely," value, in the judgment of those making the estimates for the ISFM data base, was $45,000 per package, which is higher than but much closer to DOE's estimate. The reason the average or "expected" value of the probability distribution is higher than the modal or "most likely" value is that those persons who encoded the data base assigned a "maximum," or 90 percent, value of $150,000 per waste package. They assigned this value because they believed there was a great deal of uncertainty about the materials and technology that eventually might be required to meet the repository license requirements. As a consequence, the average or expected value of the probability distribution is "pulled" considerably above the modal value.

The State of Tennessee's cost analyses also use a probabilistic approach, which, although different from the one used to construct the ISFM data base for WACUM, also yields higher estimates than DOE's analysis.[19] This basic difference in the approach to cost estimating is most relevant in explaining the differences in the estimates of the costs of the repository and the MRS facility, where the development of new technologies and the consequences of evolving regulatory and licensing issues are most prevalent.

Table 6.5 shows the probability distributions for the totals and cost components for the same three cases (No-MRS, linked MRS, unlinked MRS) and repository start schedules (2003, 2013, 2023) used in Table 6.4. The total costs are the underlined numbers in each column. The probability levels were estimated by WACUM, using Monte Carlo simulation.[20] This technique uses a large number of iterations to construct a distribution describing the probability that the system's total costs and its components will fall above or below a particular value. Individual cost account values are selected for inclusion in a particular iteration based on the probability they were assigned in the encoded data base. That is, about 10 percent of the time the minimum value for an individual cost account will be included in an individual iteration and about 10 percent of the time the maximum or 90 percent value will be included. Eighty percent of the time the average value (EV) is selected. The figure's three columns, 10 percent, EV, and 90 percent contain values in billions of constant 1989 dollars. The EV column in Table 6.5 is the same as the WACUM column in Table 6.4. The percentages have the same meaning as explained in Section Two, Part A.2, above.

The uncertainty in the estimates for the 90 individual cost accounts is reflected in the very wide range between the 10 and 90 percent levels for the totals. The wider the individual cost account ranges, the wider the distribution ranges for the totals. The breadth of the range might suggest extreme uncertainty but it might be noted that the difference between the initial cost estimates and final cost of completion for most large nuclear facilities is much greater than the range in Table 6.5. For every case analyzed, the expected value of the total system costs is within the range estimated for every other case, although the overlap is quite small in the case of the lowest cost case (No-MRS, repository in 2003) and the highest cost case (linked MRS in 2020, repository in 2023); the expected value of $24.8 billion in the No-MRS, repository in 2003 case barely exceeds the $24.0 billion lower limit in the linked MRS in 2020, repository in 2023 case.

Considerably more disparity is evident in some of the cost components. The low end of the range for at-reactor costs in all three of the No-MRS cases exceeds the upper end of the range of the three unlinked MRS cases (shown in the far right column). In both cases in which the repository is delayed (the 2013 and 2023 panels), the expected value MRS costs in the linked strategy fall below the lower end of the range of MRS costs estimated for the unlinked MRS strategy. Since the same volume of spent fuel will have to be transported and emplaced in the repository in all cases, as might be expected, little variation is observed between the cost categories in the cases shown in the table. In general, however, the comparison of the expected values and the estimated ranges shows that uncertainty in the underlying cost data is so great that it is hard to be very confident that the differences observed in the estimates are significant.

The DOE estimates, listed in Table 6.4, fall within the range projected by WACUM in Table 6.5, although, as the preceding discussion indicates, this may be more a function of averaging and off-setting assumptions than any sort of mutual validation of the two sets of estimates.

These comparisons are not intended to show that one set of estimates is more "correct" or "accurate" than another. Using different data and methods to estimate the building and operating costs for first-of-a-kind facilities that probably will not be built until well into the next century should not be expected to result in closely comparable estimates. Rather, these comparisons are intended to illustrate the nature of the differences among the estimates and the degree of uncertainty inherent in them.

Section Three: Cost Analysis

Table 6.6 summarizes the estimated costs of three components of the spent fuel management and disposal system for some of the cases that the Commission evaluated. The first column, MRS Cost, includes the estimated costs for designing, constructing, and operating a storage-only or "basic" monitored retrievable storage facility, which does not package or consolidate spent fuel. The second column, Federal Cost, includes all cost estimates the Federal government would pay out of the Nuclear Waste Fund. Included are the cost of the MRS facility (in column 1), the repository(ies), transportation, payments to States or local governments, and program management. The third column, At-reactor Cost, records the estimated costs for managing and storing spent fuel at reactors, paid for by utilities directly. The costs of delaying the removal of spent fuel from shutdown reactors are included as a component of at-reactor costs. As explained above, DOE does not include these costs in its estimates. The fourth column, Total

Table 6.5—Comparison[a] of 10% and 90% Probability Levels[b] For Total-system Life-cycle Costs: Selected Cases (Billions of Constant 1989 Dollars)

YEAR REPOSITORY STARTS	NO-MRS			LINKED MRS (NWPAA)[c]			UNLINKED MRS[d]		
	10%	EV[b]	90%	10%	EV[b]	90%	10%	EV[b]	90%
2003									
TOTAL	20.4	24.8	30.2	20.9	26.9	34.3	21.4	27.0	33.9
At-Reactor	1.9	2.3	2.7	0.9	1.2	1.6	0.7	0.9	1.2
Development & Evaluation[e]	NM[f]	NM	NM	NM	NM	NM	NM	NM	NM
Transportation	2.6	3.7	5.0	2.6	3.7	5.1	2.6	3.8	5.1
Repository	7.0	9.7	13.1	6.6	9.7	13.4	6.9	9.7	13.2
MRS	—	—	—	1.6	2.5	3.6	1.8	2.8	3.9
2013									
TOTAL	22.2	26.6	32.4	22.7	27.9	33.9	21.4	26.7	33.0
At-Reactor	4.6	5.1	5.8	3.3	3.7	4.2	0.9	1.1	1.4
Development & Evaluation[e]	NM	NM	NM	NM	NM	NM	NM	NM	NM
Transportation	2.3	3.3	4.5	2.4	3.3	4.3	2.4	3.3	4.3
Repository	6.6	9.2	12.7	6.6	9.2	12.3	6.5	9.2	12.4
MRS	—	—	—	1.3	2.1	2.9	2.2	3.2	4.4
2023									
TOTAL	23.8	28.0	33.1	24.0	29.5	35.6	21.5	27.2	33.7
At-Reactor	6.0	6.6	7.4	5.2	5.9	6.6	1.1	1.4	1.7
Development & Evaluation[e]	NM	NM	NM	NM	NM	NM	NM	NM	NM
Transportation	2.1	2.9	3.8	2.0	2.9	3.8	2.0	2.8	3.6
Repository	6.9	9.4	12.6	6.6	9.4	12.6	6.5	9.4	12.8
MRS	—	—	—	1.1	1.7	2.4	2.5	3.7	5.0

[a] Source, Table 6.4, assumes one 87,000 MTU repository and an efficient (RRK) pick-up rule. See Appendix G for acceptance schedules.

[b] Based on a 500 iteration Monte Carlo simulation using the WACUM encoded data base, "10%" means there is a 0.1 probability the number will be less than the value indicated and "90%" means there is a 0.9 probability the number will be less than the value indicated. "EV" is the expected value and the mean of the probability distribution.

[c] MRS is to begin operations three years before the repository.

[d] MRS is to begin operations in the year 2000 and is not subject to an inventory constraint.

[e] A probability distribution was not estimated for the preponderance of cost, reported in this category, therefore a Monte Carlo simulation would not yield meaningful results.

[f] NM indicates not meaningful.

Table 6.6—Comparison of Total-system Life-cycle Costs for Selected Repository Start Dates[a] (Billions of Constant 1989 Dollars)

	(1) MRS Cost	(2) Federal Cost	(3) At-reactor Cost	(4) Total Cost
Panel One: Repository in 2003				
No-MRS	—	22.5	2.3	24.8
Linked MRS 2000[b]	2.5	25.7	1.2	26.9
Unlinked MRS 1998[c]	2.9	26.3	0.7	27.0
Unlinked MRS 2000[c]	2.8	26.1	0.9	27.0
Panel Two: Repository in 2013				
No-MRS	—	21.5	5.1	26.6
Linked MRS 2010[b]	2.1	24.2	3.7	27.9
Unlinked MRS 2000[c]	3.2	25.6	1.1	26.7
Unlinked MRS 2008[c]	2.7	24.9	2.2	27.1
Panel Three: Repository in 2023				
No-MRS	—	21.4	6.6	28.0
Linked MRS 2020[b]	1.7	23.6	5.9	29.5
Unlinked MRS 2000[c]	3.7	25.8	1.4	27.2
Unlinked MRS 2010[c]	3.1	25.1	3.2	28.3

[a]Source: Table 6.4.
[b]Three-year schedule linkage and inventory limit of 15,000 MTU per NWPAA.
[c]No inventory limit.

Cost, contains estimates of the total system costs, the sum of columns 2 and 3.

The table is divided into three panels. The first summarizes the estimates for cases that assume, in accordance with the Department of Energy's current goal, that a repository would be operational in 2003. Cases summarized in the second panel assume that a repository would be delayed until 2013, and those in the third assume it is delayed until 2023.

The cases summarized include No-MRS, a linked MRS, and an unlinked MRS system.[21] The linked MRS is assumed to be linked as specified in the NWPAA, in which the MRS and repository schedules are linked, and the MRS inventory is limited to 15,000 MTU.[22] The unlinked MRS systems analyzed here are constrained by neither schedule linkage nor inventory limit.

Table 6.6 captures only a few of the parameters used to characterize spent fuel alternatives' cost. Additional factors could be varied to produce different cost estimates; for example, one could assume a variety of additional functions that could be performed at an MRS, phased construction of an MRS, whether or not spent fuel is consolidated, various MRS locations, alternative strategies for shipping fuel from western reactors, the use of dual-purpose or universal casks, whether one or two repositories are built, and alternative schedules for generating and accepting spent fuel. Some of these factors are discussed elsewhere in this report, but the analysis here considers only DOE's currently preferred alternative, the basic or storage-only MRS, under different assumptions about the timing of the repository. Table 6.6 illustrates how the costs of several spent fuel management alternatives would change as the repository start date is delayed and how changes in the date affect judgments about choices among alternatives. The principal points to notice are:

- At-reactor storage costs increase if the repository is delayed. The most dramatic increase occurs after significant numbers of reactors reach the end of their operating lives and are shut down. Five years after a reactor is shut down, all fuel can be removed and significant security and spent fuel management costs can be avoided if an MRS or a repository is open and has adequate capacity to accept the fuel.
- MRS costs increase if the repository were delayed and the facility is not linked to the repository. MRS costs increase because it must operate longer.
- In the No-MRS case, the increase in at-reactor storage costs was less than the costs of adding an MRS to the system until many reactors reached the end of their operating lives and were shut down. If the repository is delayed beyond 2015, the costs of a No-MRS system and an unlinked MRS system that begins to accept fuel in 2000 become approximately the same measured in undiscounted dollars.

The trade-off between increased at-reactor storage costs and the costs of including an MRS in the system is a principal determinant of the cost differences among alternative strategies. For example, in Panel One of Table 6.6, repository in 2003, at-reactor storage costs in the No-MRS case are estimated to be $1.4 billion more than the case in which an unlinked MRS would begin operating in 2000. However, the increased cost for at-reactor storage amounts to only 50 percent of the $2.8 billion required to add an MRS to the system.

In Panel Two, repository in 2013, the difference between at-reactor costs in the No-MRS case and in the unlinked MRS available in 2000 is $4 billion, almost triple the difference for cases in 2003, and exceeding the $3.2 billion it would cost to add the MRS to the system. Development and evaluation costs, however, are $0.8 billion lower ($9.8 billion minus $9.0 billion) in the No-MRS case, as can be seen in Table 6.4, so the total cost for the No-MRS system is still slightly below the cost for the MRS system.

In Panel Three of Table 6.6, repository in 2023, additional at-reactor storage costs incurred in the No-MRS case exceed the cost of including an unlinked MRS available in 2000 in the system, as well as the additional D&E costs, and the MRS system is less expensive than the No-MRS system.

Comparisons between a No-MRS alternative and a linked MRS alternative show that the cost advantage of the No-MRS system persists in all the cases compared, with additional at-reactor storage costs always less than the cost of adding an MRS facility to the system.

Although total costs do not vary greatly, even when considering quite extreme cases, the differences in the incidence and distribution of the cost components are significant. In the unlinked MRS case, the cost to be paid directly by utilities would be only a little more than 20 percent ($1.1 billion / $5.1 billion) as much as it would be in a No-MRS system, in both the 2013 and the 2023 cases. It could be argued that since the Nuclear Waste Fund is derived from levies on nuclear-generated electricity, therefore paid for by the ratepayers of nuclear utilities, this fact is irrelevant. However, as was discussed previously, the distribution of at-reactor storage costs among utilities will vary quite significantly depending on their age and design. Moreover, from the perspective of the planning horizon used by the current management of utilities, the fee the utility must pay into the Nuclear Waste Fund is fixed by law, and the amount the utility will have to pay into the fund is largely outside the utility's direct control. Within this planning horizon, the proportion of the national spent fuel management and disposal system's costs which the Fund finances will not affect the utility's financial performance. However, utility-paid at-reactor storage costs will affect the utility's financial performance. Therefore, utilities have an economic incentive to favor spent fuel management alternatives that reduce at-reactor storage costs.

Section Four: The Effects of Discounting

A dollar received today is more valuable to an individual or the government than a dollar received a year from now. Conversely, a cost incurred a year from now is less onerous than a cost incurred today. The principle involved is simple: Abstracting from inflation, a dollar deposited in a savings account paying 4 percent today, for example, will have earned four cents in interest in a year. Thus, no one would trade a dollar available today for any less than a dollar and four cents available a year from now. For the Federal government or an individual to make rational decisions about how resources should be allocated, differences in the value of those resources over time must be accounted for. The accepted way to do this is to discount future income or costs at a rate which reflects the value or cost which would have been received had the dollars been available today. The discounted value is called the "present value." The higher the discount rate used to compute the present value the lower the present value will be, all else being equal.

Opinions differ about the appropriate rate of discount to be used in comparing alternatives through time, but most experts agree that discounting should be done.[23] Since the costs considered here are adjusted to correct for expected inflation (that is, since "constant dollars" are used in all calculations), the discount rate reflects only the implied value of the resources foregone and does not reflect expected increase in price.

DOE's cost studies have traditionally been reported in undiscounted, constant dollars, so the Commission used undiscounted dollars to make its studies comparable to DOE's. However, because the spent fuel management and disposal system's benefits and costs will be incurred at different points in time under different alternatives and cases, the Commission made cost comparisons based on present value and on an undiscounted current, or nominal, value basis.

Tables 6.7 and 6.8 compare the costs of the alternatives and cases previously discussed.

Discounting results in modest increases in the relative cost advantages of the No-MRS alternative over the unlinked MRS system as the repository is delayed. On a nominal value basis, a system without an MRS is estimated to have almost the same total system cost as one with an MRS if the repository is delayed to 2013 and is slightly less expensive by 2023. On a present value basis, the No-MRS system retains its cost advantage of about 6 percent as the repository is delayed in both the 2013 and 2023 cases. The major cost account increasing the cost of No-MRS cases is the increase attributable to the delay in removing spent fuel from shutdown reactors. The preponderance of this cost occurs after 2015, as Figure 6.3 illustrates. The figure shows the annual costs for delaying the removal of spent fuel from shutdown reactors in both nominal and present value terms for a No-MRS case in which the repository is delayed until 2023. In nominal value terms, the annual cost of delaying spent fuel removal from shutdown reactors peaks in 2037 at $145 million but the present value of the cost in 2037 is only about $22 million.

Compared to a linked MRS system, the cost advantage of the No-MRS alternative remains at about 5 percent, regardless of whether the comparison is based on the nominal or present value. Recalling the analysis of the uncertainty of the cost estimates shown in Table 6.5, cost differences of this magnitude clearly are small relative to the inherent uncertainty in the cost data from which they were derived.

Discounting the at-reactor storage costs decreases the relative importance of the cost of the at-reactor storage component that is attributable to the removal delay, but the relative importance of the total at-reactor storage category in total system costs remains unchanged. In the linked MRS cases, delaying the repository opening reduces the relative cost of the MRS because the facility is built later with "cheaper" discounted dollars, and this tends to reduce the cost advantage of the unlinked MRS compared to the linked MRS.

In general, however, discounting does not significantly change the relationships among the costs of alternatives. Systems without an MRS are less expensive if the repository comes on line as scheduled; if the repository is delayed, the cost differences shrink as at-reactor storage costs accumulate.

Table 6.7— Comparison of Total-system Life-cycle Costs for Selected Repository Start Dates:[a] Present Value[b] and Nominal Value[c]

	(1) MRS Cost		(2) Federal Cost		(3) At-reactor Cost		(4) Total Cost	
Panel One: Repository in 2003	Nominal Value	Present Value	Nominal Value	Present Value	Nominal Value	Present Value	Nominal Value	Present Value
No-MRS	—	—	22.5	10.6	2.3	1.0	24.8	11.6
Linked MRS 2000[d]	2.5	0.9	25.1	11.9	1.2	0.6	26.9	12.5
Unlinked MRS 1998[e]	2.9	1.2	26.3	12.1	0.7	0.5	27.0	12.6
Unlinked MRS 2000[e]	2.8	1.1	26.1	12.0	0.9	0.5	27.0	12.5
Panel Two: Repository in 2013								
No-MRS	—	—	21.5	7.4	5.1	1.8	26.6	9.2
Linked MRS 2010[d]	2.1	0.6	24.2	8.2	3.7	1.5	27.9	9.7
Unlinked MRS 2000[e]	3.2	1.2	25.6	9.1	1.1	0.6	26.7	9.7
Unlinked MRS 2008[e]	2.7	0.8	24.9	8.6	2.2	1.1	27.1	9.7
Panel Three: Repository in 2023								
No-MRS	—	—	21.4	5.4	6.6	2.0	28.0	7.4
Linked MRS 2020[d]	1.7	0.3	23.6	5.8	5.9	2.0	29.5	7.8
Unlinked MRS 2000[e]	3.7	1.3	25.8	7.2	1.4	0.7	27.2	7.9
Unlinked MRS 2010[e]	3.1	0.8	25.1	6.5	3.2	1.4	28.3	7.9

[a]Source: Table 6.4.
[b]Present value is in billions of constant 1989 dollars discounted at an annual rate of 4%.
[c]Nominal value is in billions of constant 1989 dollars.
[d]Three-year schedule linkage and inventory limit of 15,000 MTU per NWPAA.
[e]No inventory limit.

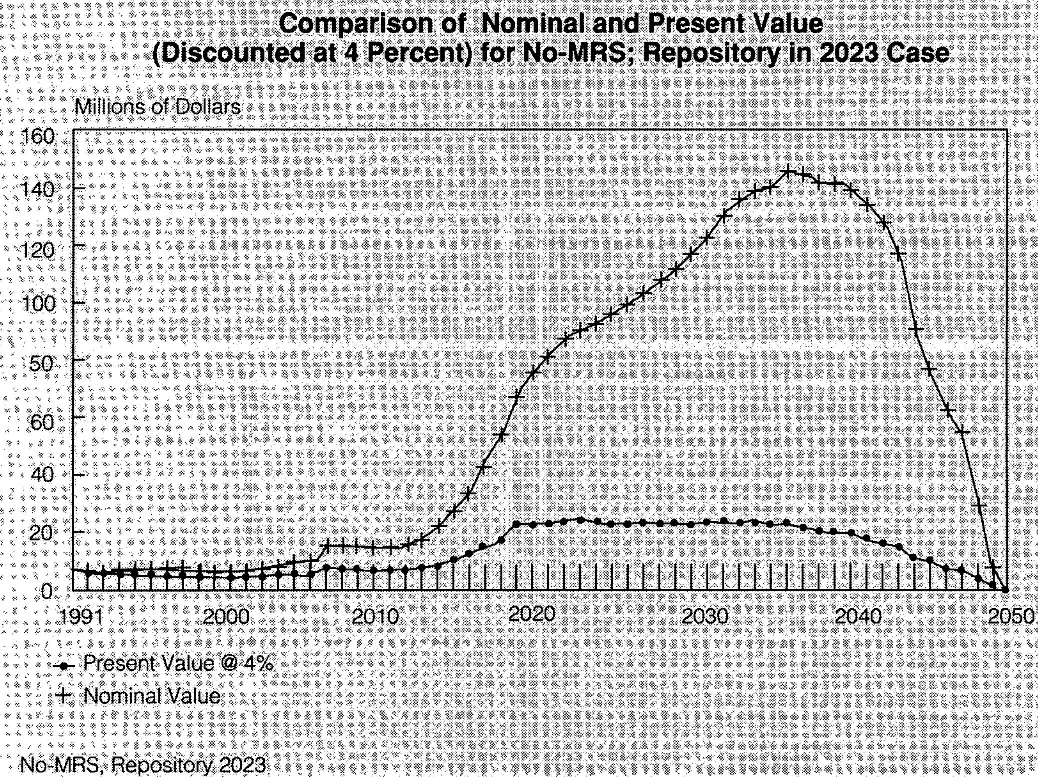
7 0 2 3 0 2 1 1 6

Table 6.8 — Comparison of Total-system Life-cycle Costs:[a] Nominal Value and Present Value[b] for Selected Cases

Year Repository Starts	No-MRS PV	No-MRS NV	Linked MRS[c] PV	Linked MRS[c] NV	Unlinked MRS[d] PV	Unlinked MRS[d] NV
2003						
TOTAL	11.6	24.8	12.5	26.9	12.5	27.0
At-reactor	1.0	2.3	0.6	1.2	0.5	0.9
[Shutdown Reactors][e]	[0.4]	[1.2]	[0.2]	[0.5]	[0.1]	[0.2]
Development & Evaluation	6.3	9.0	6.6	9.8	6.6	9.8
Transportation	1.0	3.7	1.1	3.7	1.7	3.8
Repository	3.2	9.7	3.2	9.7	3.2	9.7
MRS	—	—	0.9	2.5	1.1	2.8
2013						
TOTAL	9.2	26.6	9.7	27.9	9.7	26.7
At-reactor	1.8	5.1	1.5	3.7	0.6	1.1
[Shutdown Reactors][e]	[0.6]	[2.7]	[0.4]	[1.3]	[0.1]	[0.3]
Development & Evaluation	4.8	9.0	5.0	9.7	5.1	9.8
Transportation	0.6	3.3	0.6	3.3	0.8	3.3
Repository	2.0	9.2	2.0	9.2	2.0	9.2
MRS	—	—	0.6	2.1	1.2	3.2
2023						
TOTAL	7.4	28.0	7.8	29.5	7.9	27.2
At-reactor	2.0	6.6	2.0	5.9	0.7	1.4
[Shutdown Reactors][e]	[0.7]	[3.6]	[0.6]	[3.0]	[0.2]	[0.5]
Development & Evaluation	3.8	9.0	3.8	9.6	4.1	9.9
Transportation	0.4	2.9	0.4	2.9	0.5	2.8
Repository	1.3	9.4	1.3	9.4	1.3	9.4
MRS	—	—	0.3	1.7	1.3	3.7

[a] Source: Table 6.4.
[b] Nominal value (NV) is in billions of constant 1989 dollars; present value (PV) is in billions of constant 1989 dollars discounted at an annual rate of 4%.
[c] MRS is to begin operations three years before the repository and to be limited to 15,000 MTU per NWPAA.
[d] MRS is to begin operation in the year 2000 and to have no capacity limit.
[e] Cost of delaying the removal of spent fuel from shutdown reactors. This is included as a part of "At-reactor" storage costs.

Figure 6.3—Cost Per Year Of Delayed Removal Of Spent Fuel From Shutdown Reactors



Section Five: Findings

The Commission finds that the costs of building and operating an MRS are greater than the savings in at-reactor storage costs if the repository starts according to current DOE schedules or is subject to a modest delay. If the MRS is delayed beyond 2013, when the cost of delaying the removal of spent fuel from shutdown reactors begins to accumulate, then the cost differences between a No-MRS and unlinked MRS system become negligible.

Since the criteria that the Commission used to evaluate the desirability of including a monitored retrievable storage facility in the national spent fuel management and disposal system are not limited to lowest cost, these data do not demonstrate conclusively that a No-MRS strategy is to be preferred, even if one is optimistic about the repository schedule. Moreover, the uncertainty apparent in the cost data suggests it would not be prudent to base decisions primarily on what is currently perceived to be the lowest cost strategy.

Chapter Six Notes

1. Department of Energy, "Analysis of the Total-Systems Life-Cycle Cost for the Civilian Radioactive Waste Management Program," for years 1983 through 1989.

2. The most significant changes occurred between the 1987 and 1988 estimates as a result of the passage of the 1987 Amendments to the Nuclear Waste Policy Amendments Act of 1987. As previously described, these amendments directed the Department of Energy to make a number of changes in its basic plan for developing the waste system, and the cost consequences of these changes were included for the first time in the 1988 report. The intent of the NWPAA was to reduce the cost of the system by reducing the number of alternative sites to be studied, or "characterized," as to their suitability as a location for a repository. The TSLCC report estimates that these changes reduced the lifetime cost of the system by $5.6 billion. At the same time, DOE included in its 1988 estimates the benefits to be paid to States and localities affected by the repositories and the MRS, according to the schedule included in the NWPAA, which amounted to $0.9 billion. Along with other more minor changes the net effect of the 1987 amendments, according to DOE, was to decrease the cost of the system by $5.9 billion. As in previous years, the Department also made changes in design and planning assumptions which increased total system costs between 1987 and 1988. For a system that is comparable to the one reflected in the 1987 estimates, these changes, along with an adjustment for inflation, amounted to $5.8 billion, so the net effect was to leave the estimate of the total cost of the system virtually unchanged. Department of Energy, "Analysis of the Total-System Life-Cycle Cost for the Civilian Radioactive Waste Management Program," DOE/RW-0236, May 1989 **(Hereafter cited as TSLCC 1989)**, pp. 1–8, 1–9.

3. Department of Energy, "Summary Report of the MRS System Studies," May 1989. **(Hereafter cited as Task J)**

4. TSLCC 1989, p. 6–7. The basic MRS, in DOE's proposal, would retain the option to conduct packaging and consolidation should future developments or information make that desirable. The cost savings discussed in the TSLCC report, however, assume that packaging and consolidation do not become practical and the MRS remains only a storage and staging facility throughout its useful life.

5. TSLCC 1989, p. 1–10. Such a change would require an amendment to the NWPA which imposes a 70,000 MTU limit on the first repository.

6. TSLCC 1989, p. 1–6.

7. TSLCC 1989, p. 1–1.

8. Dershowitz, W., Breeds, C., Roberds, W., and Miller, I., "Interim Spent Fuel Management Cost Data Base: Report to Monitored Retrievable Storage Review Commission," Seattle: Golder Associates, 1989 (893-1032.120) **(Hereafter cited as ISFM Cost Data Base)**.

9. ISFM Cost Data Base, pp. 22–31.

10. Miller, I., and Fuget, W., "WACUM: Nuclear Waste Cost Database and Simulation Model User's Guide Version 1.13: Report to the Monitored Retrievable Storage Review Commission," Seattle: Golder Associates, 1989.

11. In its system studies, DOE discussed the effects of the OFF pick-up rule on costs and showed that it would lead utilities to incur greater at-reactor storage costs than a more efficient rule. The data reported in the Task J and TSLCC reports, however, are derived using OFF.

12. "Full" means that any additional storage of spent full would encroach on a reserve adequate to store the reactor's operating core should that be necessary.

13. The DOE estimates summarized in the table were made by DOE at the Commission's request assuming that all the spent fuel generated would be emplaced in one repository. As noted previously, the NWPA would have to be amended to do this. There is a great deal of uncertainty about the second repository schedule and the type of geologic medium in which it would be built. Basing the estimates on the assumption that all spent fuel would be emplaced in one repository is an analytic device employed here in an attempt to prevent the uncertainty associated with a second repository from reducing the comparability of the estimates. The DOE estimates were converted from 1988 dollars to 1989 dollars by use of the Implicit GNP Deflator, which increased at an annual rate of 4 percent in 1988 and at an annual rate of 4.4 percent in the first two quarters of 1989. "U.S. Financial Data," St. Louis Federal Reserve Bank, July 29, 1989.

14. "WACUM Versus DOE Systems Study Comparison," Golder Associates, Inc., September 1989, p. 4.

15. Wood, T., et al., "MRS Systems Study Task G Report: The Role and Functions of Surface Storage of Radioactive Material in the Federal Waste Management System," Pacific Northwest Laboratory, PNL-6876 **(Hereafter cited as Task G)**, pp. 3.16–3.22.

16. The costs are included in the at-reactor total.

17. The costs used were taken from the Task G Report, pp. 3.21 and 3.22, specifically, $2.2 million per year for a site with one or two shutdown reactors, $2.7 million for a site with three shutdown reactors, $410,000 for one shutdown reactor at a site which also has an operating reactor and $610,000 for a site with two shutdown reactors and an operating reactor. The costs included in the original encoded ISFM data base were higher, ranging from a low or "10 percent" estimate of $2 million per year per site to a high or "90 percent" estimate of $5 million per year per site. These costs do not start accumulating until all the spent fuel at the reactor is at least five years old and, thus, could be sent to a repository or an MRS if it were available.

18. DOE essentially treats D&E costs as fixed costs which continue to accumulate at a more or less fixed rate if the repository is delayed. Although this may a realistic reflection of the budgetary response observed in the real world for fairly short term delays, it is not an appropriate assumption to use in modeling the waste system costs over a 40- or 50-year planning horizon. Because D&E costs are a large component of total costs, such an assumption reduces the credibility of the cost estimates as a whole.

19. Hoskins, R., "A Systems Evaluation of the High-Level Nuclear Waste Management System Based on Integration of Dual Purpose Cask Into the System as an Alternative to DOE'S Proposed Monitored Retrievable Storage Facility as an Integral Part of the System," Knoxville, Tennessee: University of Tennessee Waste Management Research and Education Institute, 1989, pp. V–25 to V–39. See also Hoskins, R., "Probabilistic Assessment of Nuclear Waste Fund Fee Adequacy," *Waste Management '88* for an explanation of a probabilistic approach to cost estimation and decisionmaking.

20. The simulation was a restricted Monte Carlo simulation made with triangular probability density functions containing only the minimum, expected, and maximum values.

21. All MRS estimates assume that the MRS is located in the Southeastern United States and that the repository is located in Nevada. A "western strategy" is also assumed which means that reactors located west of 100 degrees longitude ship their spent fuel directly to the repository while reactors east of that line send spent fuel to the MRS. In scenarios in which the MRS comes on-line before the repository opens, the WACUM cost simulation model keeps track of the fuel that western reactors would have been allowed to ship under the operative pick-up rule if they would have been permitted to ship to the MRS and gives this fuel first priority to ship to the repository once it opens.

22. If the MRS has reached its capacity limit but the repository has not, the WACUM cost simulation model allows reactors to by-pass the MRS and ship directly to the repository. This assumption reduces the cost of the MRS compared to an assumption which requires all spent fuel to be passed through the MRS facility.

23. Lind, R., *Discounting for Time and Risk in Energy Policy*, Washington, D.C.: Resources for the Future, 1982, presents a complete discussion of the importance and methods of discounting in public policy.

Chapter Seven
Distributional Considerations and Equity

This chapter discusses the distribution of the costs and effects of the national spent fuel management system. "Distribution" refers to the incidence of costs and effects: which individuals or governing bodies pay which costs, and who is affected by the siting, construction, and operation of facilities in the system. "Equity" means the fairness or justice of the distribution. The spent fuel management system's distribution of costs to, and effects on, individuals has not been as completely analyzed as have the system's technological and logistical aspects. However, these distributional and equity concerns have played an important role in the controversy surrounding MRS proposals. Concerns include which regions of the United States would have access to an MRS and in which region an MRS should be built.

Although it is common to discuss costs to governments or to businesses, all costs and risks are ultimately borne by individual citizens, consumers, ratepayers, taxpayers, or stockholders.

Section One of this chapter discusses compensation to States and localities for costs and risks their citizens might incur if an MRS or a repository were located in their jurisdiction. Section Two discusses problems that may arise from "stigma effects"—the economic and psychological effects of perceptions about nuclear waste facilities. Section Three considers equity issues. Section Four discusses some of the efficiency and equity aspects of the arrangements used to finance the system. Section Five presents the MRS Review Commission's findings.

Section One: Compensating State and Local Governments

The Nuclear Waste Policy Amendments Act of 1987 (NWPAA) outlined payment schedules intended to compensate States, localities, or Indian Tribes for additional burdens on services or infrastructure that locating an MRS or repository in their jurisdiction might create. For example, roads surrounding the MRS might have to be upgraded, the police force might have to be increased, and the school system might have to be enlarged. Although some Members of Congress advocated annual compensation as high as $100 million per year to States or Indian Tribes in whose jurisdictions a repository was located, and $50 million per year for hosting an MRS facility,[1] the NWPAA included a lower compensation schedule. The NWPAA specifies compensation for repositories of $10 million per year until spent fuel is accepted and $20 million per year thereafter; for the MRS, the act allows $5 million per year until operations start and $10 million per year thereafter.[2]

The NWPAA directed the Department of Energy (DOE) to limit its efforts to characterize a repository site to the Yucca Mountain site in Nevada and specified what a State or Indian Tribe benefit agreement should contain. Among the specified provisions is a requirement that the State or Tribe signing such an agreement waive its right to disapprove the repository site recommendation. DOE asked the State of Nevada to enter into negotiations to fashion a compensation agreement but Nevada declined.[3]

DOE has testified that it would prefer to locate an MRS through direct negotiations between the Office of the Nuclear Waste Negotiator and individual States in hopes of bringing the facility on line sooner than the current linkages permit.[4] If the negotiations were successful, and if Congress approved the negotiated agreement, the cost of compensating the State might be greater than the NWPAA specified.

In theory, identifying governmental service burdens and costs and arranging efficient compensation mechanisms should be straightforward because these burdens and costs are fairly concrete and quantifiable, like roads, schools, and police. If successfully executed, the compensation would offset any inequities created for States, localities, or Tribes. Such compensation or mitigation programs have been designed and implemented successfully as a part of large construction projects, such as power plants and oil pipelines.[5] However, in practice, determining appropriate compensation to State and local governments or Indian Tribes may involve complex and contentious negotiation.

Section Two: Stigma Effects

Regardless of their size, payments to States, localities, or Indian Tribes affected by an MRS's or repository's location may not mitigate all of the cost of siting and its effects on individuals. For example, the negative images that nuclear waste facilities engender may create costs for individuals that may not be administratively practical or desirable to fully compensate. Experts may not agree with the public's perception of risk on which the negative images of nuclear waste facilities are based, but if the population widely shares these images, the resulting costs may be real and significant. Such costs may be directly monetary, such as a decline in property values; they may be less direct but still economic, such as a change in the community's or State's appeal as a place to live, work, or locate a business; or they may be more psychological than economic, the manifestation of increased anxiety and apprehension of neighboring citizens. These costs are referred to as "stigma effects." Although concern about stigma effects has played a significant role in the MRS debate, there is no objective, agreed-upon method to measure and compensate for them. Nor is there agreement on whether or not such compensation is necessary or desirable.

Payments to States, localities, and Indian Tribes may be partly premised on stigma effects, or a negotiated agreement may explicitly acknowledge them, but it still may not be feasible, practical, or desirable to compensate the individuals that incur them. For example, if an offer were made to compensate those who suffered increased anxiety because a nuclear waste facility was located in their neighborhood, it would be administratively impossible to distinguish those truly experiencing increased anxiety from those merely wanting to be compensated.

A related difficulty is that much of the stigma associated with nuclear waste facilities is the result of individuals' perceived risks which appear to exceed by orders of magnitude the experts' estimate of risks, as discussed in Chapters Four and Five. Policy should respond to risks which reflect the best information available. But the dilemma for policymakers is that although the costs are real, the perceptions of risk that create them may be the product of misinformation or varying value systems.[6]

Stigma effects played an important role when Tennessee objected to DOE's initial proposal to locate an MRS in that State. Lamar Alexander, then governor, argued that locating an MRS facility at an Oak Ridge site would be detrimental to the State's aspirations for "high tech" economic development to cluster around the Tennessee Technology Corridor between Oak Ridge and Knoxville.[7]

A survey of civic and business leaders by the University of Tennessee's Center for Business and Economic Research indicated that DOE's proposal to locate an MRS in Oak Ridge evoked negative images, but no attempt was made to determine the dollar cost associated with them.[8] Similarly, Nevada's Socioeconomic Advisory Panel studied comparable effects associated with the proposed Yucca Mountain repository site and concluded that although they could not quantify the stigma effects' magnitude, they believed the effects existed and might be significant.[9]

Studies also show that building an MRS offers individuals economic benefits that offset stigma effects. Communities close to an MRS would benefit economically during the facility's construction and operation. Tennessee's studies estimated that such benefits would amount to approximately $115 million per year in additional wages and salaries during the construction of the facility and $37 million per year in additional wages and salaries during its operation. The studies estimated that about 700 permanent jobs would be associated directly with the facility, and 560 jobs would be associated with the increased economic activity it would create.[10]

The broadly based Clinch River MRS Task Force, after comprehensive consideration, agreed on a set of conditions, including compensation, mitigation, local participation, and procedural safeguards, which they believed would make the MRS acceptable to the community.[11]

Section Three: Equity Considerations of MRS Alternatives

The Commission's discussion of the need for an MRS considered equity among localities, States, regions, and ratepayers of different utility systems. The Commission considered such questions as whether it is fair for some people, some regions, and some companies to bear the costs of spent fuel management while others do not, and how unfairness can be avoided or compensated.

Since the number of facilities in the national spent fuel management and disposal system is small (perhaps only one repository), the stigma effects associated with spent fuel management will be focused on a small number of communities and States once spent fuel is moved away from the reactors. Without an MRS, individual reactor sites will continue to accumulate spent fuel which, over an extended period of time, may also impose stigma effects. But thus far, MRS alternatives, rather than the No-MRS alternative, appear to be directly evoking the most equity concerns.

A. Equity in the Siting Process

For the imposition of the costs associated with stigma effects to be considered equitable, most analysts contend that the *process* used to select the facility's location must be fair, objective, and nonpartisan. If an MRS, or any similar facility, is built, *some* State or locality will have to bear both the quantifiable costs and risks and the stigma effects. If an unwanted facility is built, costs and risks are inevitable, making some inequity inevitable. However, if the selection of one site over another is seen as fair, and the facility is acknowledged to be necessary to the public good, the result may be seen as equitable.

Although the State of Tennessee was careful to enumerate the costs and risks it believed would be incurred were the MRS to be located in Oak Ridge, the foundation of its objection was that DOE had short-circuited the process specified in the Nuclear Waste Policy Act to objectively and "scientifically" pick the best site for such a facility. Nevada, too, believes the process by which Yucca Mountain was selected as the focus for site characterization was politically biased and unfair.

B. Geographic Equity

1. Local or Community Equity

Although the local or community level stigma effects resulting from the location of a facility may be the most direct, they may also be the easiest to deal with. First, the facility's direct or indirect economic benefits, which are concentrated at the local level, may mitigate the stigma effect to some degree. Second, individuals with particularly strong feelings or concerns may be able to move to another community, albeit at considerable personal sacrifice, but, in many cases, without a major disruption in their employment, lifestyle, or social circumstances. It might even be possible to compensate individuals for moving expenses if they chose to move from the immediate vicinity of the facility within some limited period of time after the facility's location was announced. Although some individuals might be compensated whose desire to move was unrelated to the facility, probably few would choose to bear the inconvenience of moving simply because compensation was available.

2. Equity at the State Level

Stigma effects which are asserted to have spread their incidence across an entire State may be somewhat more tenuous to identify and also more difficult to compensate. The direct economic benefits become much more dilute as the distance from the facility increases. Moreover, individuals usually will not be able to adjust by changing their residence to an unaffected State without a major disruption in their economic and social circumstances. It also probably would not be feasible to distinguish those wishing to leave a State because of stigma effects from those wishing to move for unrelated reasons. However, it may be possible to mitigate some State-level stigma effects by using advertising or educational campaigns aimed at firms or individuals that might be considering locating in the State or by improving transportation to address transportation safety concerns.

3. Regional Equity

Although equity among regions (such as East and West) has been an important concept in the MRS and repository controversy, the logic is murky. Any stigma effects which could be assumed to be spread over a wide, multi-State region are hard to define or identify, even conceptually. The desire for regional balance or equity may well be the expression of a political concern or defense to keep a facility from being located in a region.[12] But there is no geologic, environmental, or other objective reason why large, multi-State regions should not be considered as sites for an MRS or a repository. Exempting a broad region from consideration for a controversial facility may be a natural political accommodation, but it appears to have little to do with equity as the concept is generally understood.

C. Equity Among Ratepayers

The most straightforward application of equity principles to the spent fuel management and disposal problem is the treatment of nuclear utility ratepayers. Under current law, the MRS will be financed in the same way as the repository: from the Nuclear Waste Fund, to which utilities are required to pay fees according to the net amount of electricity they generate from nuclear power plants. Some utilities stand to benefit more than others, depending on such considerations as where an MRS is built, what services it offers, when it is built, and how the regulations governing its operation work.

If a repository were built in the West and an MRS in the East, reactors in the western States might have to store fuel on-site until the western repository could accept it, while reactors in the other regions could ship fuel to an MRS. Thus, a western utility with a filled pool would have to add dry storage facilities at its own expense, while an eastern utility could avoid those costs by shipping spent fuel to the MRS, financed by the Nuclear Waste Fund. Analysts feel this arrangement violates the "equal treatment of equals" equity principle—traditionally applied to other such governmental activities as taxation and expenditures—which says that a tax is equitable if it treats "equally situated taxpayers equally."[13]

Some degree of departure from the "equal treatment of equals" precept would be inevitable if there were an MRS. All utilities with nuclear power plants would pay into the Nuclear Waste Fund, but only some would benefit—the ones that store fuel at the MRS. Individual payments to the Fund would be greater the more electricity a utility generates by nuclear power, while the utility's benefits are greater the more spent fuel it stores at the MRS. Also, differences in the adequacy of spent fuel storage capacity at different utilities, coupled with an economically inefficient "oldest fuel first" pick-up rule, would cause some utilities to derive more benefit than others from their share of an MRS's costs.[14]

The fewer the services the MRS performs, the greater the likelihood that inequities will result. A "fully integrated" and "on-line" MRS would provide consolidation and packaging services for all spent fuel processed. Thus, at least those services would be generally distributed among utilities in proportion to their power generation. The benefits of a storage-only facility, especially if constrained by an inventory ceiling, would be limited to fewer utilities, and the disparity between the benefit received and the cost incurred would be greater from the standpoint of individual ratepayers.

Thus, the greatest potential inequity seems to be the lack of correlation between ratepayers' costs for an MRS facility and the same ratepayers' benefits from the facility, especially if the MRS's role and size were limited. Concern for regional equity, which has focused on siting effects and has received the lion's share of attention, appears to be more closely related to political considerations than to equity as the term is generally understood.

Section Four: Economic Efficiency and Equity in MRS Financing

If it were financed through the Nuclear Waste Fund, an MRS would be essentially free to an individual utility's stockholders. The MRS cost is a small enough part of the total national spent fuel management costs financed through the Fund to have relatively little effect on the utility's fee, at least over a typical utility financial planning horizon. Moreover, because the utility's payment to the Fund is mandatory, public utility commissions normally would allow the payment as an operating expense and incorporate it into the utility's rates. Thus, the ratepayers pay the fee. Under these arrangements, the utility has an incentive to favor a spent fuel management and disposal system that includes an MRS and an even stronger incentive to use an MRS.[15]

If an MRS were to be financed by a user-fee system, in which a utility's costs were based on how many units of storage (or other services) it used, the utility would have an incentive to compare the MRS costs with those of other spent fuel management options. If the cost and convenience (such as reduced time and management attention needed for spent fuel management) of using an MRS were comparable to the cost of using other options (such as rod consolidation, reracking, or dry storage at the reactor site), the utility would probably decide to use the MRS. If storage or consolidation technology were to change, making it cheaper to use another option, utility managers might decide not to use the MRS. Public utility commissions could review the choice made by the utilities' management and may or may not allow the cost to be passed on to ratepayers. Thus, the utility's stockholders would share with its ratepayers some of the financial risk involved in picking a spent fuel option.

The Tennessee Valley Authority, in testimony before the Commission, advocated user-fee financing of an MRS on both economic efficiency and equity grounds.[16] The reasons just outlined suggest that the user-fee system would produce more economically efficient choices and result in a lower cost to society than a mandatory payment system, unless other circumstances made the user-fee system impractical. These arguments are summarized below.

A. DOE/Utility Contracts

It might be argued that the existing contracts between DOE and utilities specify a mandatory system, and that since utilities have made their plans accordingly, it would be disruptive and costly to change to a user-fee system. However, a number of major changes in the technological and institutional context of the national spent fuel management and disposal system have occurred since the contracts between the utilities and the department were concluded. Schedule delays and changes have created pervasive uncertainty about the date at which the repository will be available. The NWPAA's linkages between the repository and the MRS are widely regarded by utilities, as well as others, to have decreased substantially the value of the MRS to the overall system and to utilities. Moreover, because of the linkages, any uncertainty about the repository's start date means uncertainty about the start date for the MRS.

Utilities are making plans to provide storage capacity at reactor sites on the assumption that the MRS will not be operational by 1998, and, even if it were, it would not be able to meet utility needs for out-of-pool storage. The existing degree of fluidity and uncertainty is so great that it is difficult to envision a major disruption in plans and expectations being brought about by a change in the MRS financing arrangements. The costs of the MRS constitute only about 10 percent of the total costs to be covered by the contracts between the utilities and DOE, thus the financial effect of a change in the contracts would be relatively modest.

B. Economic Efficiency

It could also be argued that user funding would not increase economic efficiency because utilities would use an MRS even if it were more expensive than other storage options because their primary motivation is to remove spent fuel from the reactor site, not to minimize storage costs. However, a user-fee system would not require utilities to store spent fuel at reactors. Utilities may have legitimate reasons for wanting to remove spent fuel from reactor sites; those reasons may not be reflected in the average costs of the alternatives. A user-fee system would enable the utility and the relevant public utility commission to know how much of a premium it was paying to remove the fuel. Information on the extent of this premium should both help the utility and the public utility commissions decide whether it is prudent and worthwhile to do so.

C. Expense

Making an MRS optional, it might be asserted, would increase costs elsewhere in the system, thus offsetting any savings in at-reactor costs due to enhanced efficiency. However, problems of this sort are easier to envision for a packaging MRS where failure to consolidate or to encapsulate spent fuel at an MRS in standardized canisters or waste disposal containers may increase costs at the repository unnecessarily. At an MRS which provides only storage and logistic services, such problems are less likely to arise. If they do, they could be offset by additional fees to be levied at the repository on "non-standard" fuel received from utilities.

D. Economy of Scale

It might be argued that not enough utilities may choose to use the services of the MRS to allow a facility of efficient size to be built. However, there do not appear to be significant economies of scale in the technology of a basic MRS beyond a minimum capacity of about 2,000 metric tons uranium.[17] As the size of an MRS increases, so does the number of hot cells and loading/unloading facilities. Dry spent fuel storage technology, by its nature, is modular. A smaller capacity facility may be easier to site, since the larger the capacity the greater the fear may be that the MRS will become a de facto repository.

Section Five: Findings

Based on the information presented here, the Commission finds:

A. Compensating State and Local Governments or Indian Tribes

Compensating States, localities, or Indian Tribes for costs they may incur if a nuclear waste facility were located in their jurisdiction may be politically contentious and practically difficult, but conceptually it is straightforward and, if correctly executed, would offset any unfair burden to State or local taxpayers.

B. Stigma Effects

Cost increases based on actual measurable impacts, however, are different from the stigma effects that result from the negative images widely associated with nuclear waste facilities. Although the costs created by stigma effects may result from perceived risks of nuclear waste facilities that some experts believe are overstated, the costs may impose burdens that violate commonly accepted principles of equity. Stigma effects at the local or community level may be easier to adjust to than stigma effects perceived at the State level, because the economic benefits of nuclear facilities are concentrated at the local level and because local individuals may have the option of moving, albeit with considerable personal sacrifice, to avoid the effects. The option to move is usually less practical at the State level.

C. Regional Equity

The concept of regional equity has played an important role in the nuclear waste disposal debate, but the logic behind the concept is murky. Some inequity is inevitable, but stigma effects are felt at the local or State level, not at a broad regional level such as "the East" or "the West."

D. User-Fee Financing

The ratepayers of different utility systems would be treated more equitably if an MRS were to be financed by user fees rather than the Nuclear Waste Fund and utilities would be encouraged to make more economically efficient choices among spent fuel storage alternatives. The case for user financing is stronger the more limited the MRS's capacity and the range of services it performs since the benefits are less widespread.

Chapter Seven Notes

1. U.S. Congress, *Hearings before the Committee on Energy and Natural Resources United States Senate on S. 839,* Part 3, 100th Cong., 1st Sess., April 29 and May 7, 1987, pp. 1–15.

2. 42 U.S.C. § 10174(a).

3. Department of Energy, "Analysis of the Total-Systems Life-Cycle Cost for the Civilian Radioactive Waste Management Program," DOE/RW-0236, 1988, p. 7-2.

4. Isaacs, Thomas H., Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE Position on the Monitored Retrievable Storage Facility," Prepared Remarks before the Monitored Retrievable Storage Review Commission, May 25, 1989, p. 5.

5. The Tennessee Valley Authority implemented formal mitigation programs for nuclear construction projects at Phipps Bend and Hartsville, Tennessee, and Yellow Creek, Mississippi, as have other utilities. Such programs are routinely included in large public works programs funded by international lending organizations.

6. See Kasperson, Roger, *et al.,* "The Social Amplification of Risk: A Conceptual Framework," *Risk Analysis,* Volume 8, Number 1, 1988, for a discussion of the perceptions of risk and the societal response mechanism.

7. Statement of Tennessee Governor Lamar Alexander, news release, January 21, 1986.

8. Fox, William, *An Economic Analysis of a Monitored Retrievable Storage Site for Tennessee,* Knoxville: Center for Business and Economic Research, the University of Tennessee, 1985 **(Hereafter cited as Fox, *Economic Analysis of MRS*)**, pp. 27–40.

9. Slovic, Paul, "Perceived Risk, Stigma, and Potential Economic Impacts of a High-Level Nuclear Waste Repository in Nevada," Presented at Waste Management '89, Tucson, Arizona, February 27, 1989.

10. Fox, *Economic Analysis of MRS,* p. 11.

11. Clinch River MRS Task Force, Position on the Proposed Monitored Retrievable Storage Facility, 1985.

12. Clarke, James McClure, U.S. House of Representatives, 11th District, North Carolina, Prepared Remarks, presented at the MRS Review Commission Public Hearings, February 17, 1989.

13. Musgrave, Richard A., *The Theory of Public Finance,* McGraw Hill: New York, 1959, Chapter 8.

14. See Chapter Six for a discussion of the inefficiency of the oldest fuel first pick-up rule and Pacific Northwest Laboratory, "MRS Systems Study Task G Report," PNL-6876, pp. 3.29–3.30.

15. Even utilities which do not expect to need the services of an MRS because, for example, they have adequate in-pool storage, would have little incentive to oppose an MRS. While availability of an MRS would not reduce their costs, their opposition to an MRS might have negatively affected their relationship with other utilities.

16. Willis, William, Executive Vice President and Chief Operating Officer, Tennessee Valley Authority, Transcript of Monitored Retrievable Storage Review Commission Public Hearings, January 17, 1989, pp. 177–179, 181–182.

17. See E. R. Johnson, Associates, for Pacific Northwest Laboratory, "1988 Federal Interim Storage Fee Study: A Technical and Economic Analysis," PNL-6727, November 1988, pp. 4.1–4.3, for a discussion of the costs of various sized storage facilities up to about 2,000 MTU.

Chapter Eight
Policy Issues

In the preceding chapters, the MRS Review Commission made important findings regarding the need for an MRS facility as part of the Nation's commercial spent fuel management program. Some of these findings are summarized as follows:

- Health, safety, and environmental effects are expected to be small and within appropriate regulatory limits whether spent fuel is stored at an MRS facility or at reactor sites.
- Radiological and non-radiological risks arising from transporting spent fuel, regardless of transport mode or method, are expected to be small and within regulatory limits, whether fuel is transported to and from an MRS facility or directly from reactors to a repository.
- If the repository were to begin operation in the year 2003 according to current U.S. Department of Energy (DOE) schedules, adding an MRS facility in the year 2000 would increase the undiscounted costs of the spent fuel management and disposal system. If the repository were to be delayed to the year 2013, the undiscounted costs of a system without an MRS facility would be slightly lower than those of a system that included an MRS that was available in the year 2000. If the opening of the repository were to be delayed until the year 2023, a system that included an MRS facility that was available in the year 2000 would be less expensive in undiscounted costs than one that did not. If the costs were discounted and expressed as present values, assuming a 4 percent rate of discount, the No-MRS case would remain less expensive than the MRS case even if the repository were delayed to 2023.
- The principal reason the economics of an MRS become more favorable if the opening of the repository were delayed beyond the year 2013 is that after that time there will be a sharp increase in the number of nuclear power plants whose current licenses will expire. If neither an MRS nor a repository is available, total costs of a No-MRS case increase substantially because of the costs of delaying the removal of spent fuel from shutdown reactors.
- The cost-related conclusions just summarized apply only to comparisons between a system without an MRS and a system with an unlinked MRS. A waste management system with an MRS subject to the current statutory linkages is more expensive than a No-MRS system in all cases.
- Distributional consequences and equity issues need to be addressed if an MRS facility is built, but are not discriminating factors in deciding between an MRS facility and at-reactor storage.
- If a non-integral storage-only MRS is built with a limited capacity, it would be more equitable to ratepayers if it were user-funded rather than financed from the Nuclear Waste Fund.

Chapters Four through Seven examined, quantitatively, ways that having or not having an MRS would affect health, safety, the environment, cost and equity. Chapter Eight examines the less quantifiable ways the two alternatives would affect spent fuel management goals: to protect health, safety, and the environment and foster economy, equity, flexibility, and stability in the spent fuel management system.

During the Commission's deliberations, DOE and the State of Tennessee presented testimony on the advantages and disadvantages of an MRS which discussed these less quantifiable policy issues extensively.[1] Recent studies by the State of Tennessee and DOE make findings similar to those in previous chapters about health, safety, and environmental effects—that is, the differences between the No-MRS and MRS alternatives are small. Although the studies agree that the transportation impacts are small in any case, the Tennessee studies assert that Tennessee's Integrated No-MRS option has the lowest impacts. The DOE and Tennessee studies conclude that a system with an MRS will be more costly than a system without an MRS, although none of the studies includes the costs of delaying the removal of spent fuel from shutdown reactors.[2] They do not agree on the amount of the cost increase with an MRS in the system, and they differ significantly on the nature and extent of the benefits to be realized by building an MRS facility. The Tennessee study assumed availability of a dual-purpose cask not licensed at this time in the United States.

Section One of this chapter presents the DOE and Tennessee public policy arguments for and against an MRS facility and the MRS Review Commission's analysis of the major points. The chapter focuses on the DOE and Tennessee arguments because Congress directed the Commission to evaluate DOE's proposal, and Tennessee has presented the most comprehensive arguments against an MRS. Section Two of this chapter presents the Commission's own summary of the advantages and disadvantages of building an MRS facility as part of the Nation's nuclear waste program, drawing on the DOE and Tennessee studies as well as on its own studies and other material gathered during the course of its evaluation.

Section One: Public Policy Views on the Need for an MRS Facility

A. Statement of DOE's Position

The Department of Energy wants to build an MRS facility as soon as possible. The MRS, as envisioned by DOE, would provide an opportunity to develop the nuclear waste management system in stages. Initially, the facility would receive and store shipments of intact spent fuel. When the repository is ready to accept waste, the MRS will serve as a transportation staging area for shipments to the repository. The facility could be expanded later to perform additional functions, such as rod consolidation or encapsulation, that might be regarded as beneficial as the system matures.

The Department of Energy supports an integral MRS because it believes the facility would better enable the department to meet its four strategic objectives of timely disposal, timely and adequate waste acceptance, schedule confidence, and system flexibility.

According to DOE, an integral MRS facility would facilitate timely disposal because the department would gain institutional and regulatory experience in siting and licensing that could be used in the repository program. An MRS could also provide experience in negotiating with a potential host State or Indian Tribe that could prove helpful in the repository program.

DOE believes the waste management system would benefit from timely acceptance of the waste. The asserted benefits include: a reduction in the number of reactor sites requiring additional out-of-pool storage; less likelihood that continued on-site storage would interfere with reactor operations or delay decommissioning; and improved system compatibility in the face of uncertain technological developments.

DOE asserts that an MRS facility would also provide schedule confidence because it would demonstrate the department's ability to accept, transport, and handle spent fuel at high annual rates. DOE states, "A firm Federal commitment to proceed with an MRS facility would enhance confidence that the Federal government is using all available means to ensure timely assumption of the Federal responsibility to accept spent fuel for disposal."[3]

DOE argues that an MRS facility would provide system flexibility. DOE defines flexibility as "the ability of the system to perform its mission when decisions must be made in the face of uncertainty or incomplete information...and the ability to redirect a project in response to changing circumstances in an effective way while still achieving the objectives."[4]

With this definition in mind, DOE reasons an MRS facility would provide insurance against future uncertainties. Should difficulties develop in the repository program, DOE could still accept waste from reactors. Furthermore, DOE argues, an MRS would add flexibility to the repository development schedule. The MRS would relieve some of the pressure to achieve milestones in the repository program in the face of technical and regulatory complexities and uncertainties and provide more time to resolve unanticipated problems. In addition, DOE states that an MRS built in stages would preserve the option of adding functions to minimize operations at the repository. Finally, DOE states that an MRS would permit management of spent fuel shipments according to technical requirements (e.g., to achieve a certain temperature distribution in the repository). If the MRS capacity were increased, spent fuel could be aged before emplacement in the repository, an option chosen by most European countries.

While DOE would prefer to build an integral MRS facility with less stringent alternative linkages, the department also sees benefits in building an integral MRS facility linked under current law to the repository schedule and limited in capacity. The department would prefer that the Nuclear Waste Negotiator site the MRS in recognition of the difficulties the department would face in undertaking such a process. In testimony before the Commission DOE stated that, "it is possible that a State or an Indian Tribe might negotiate an agreement that would allow the construction—and perhaps even operation—of the MRS facility to proceed at a faster pace than allowed by current linkages in the Amendments Act."[5]

B. MRS Review Commission's Analysis of DOE's Position

The Commission finds there is merit to many of the Department of Energy's arguments that an MRS facility would benefit the waste management system. However, the Commission believes some of the benefits would be less than DOE asserts, and there are disadvantages associated with an MRS as well.

1. Timely Disposal of Nuclear Waste

DOE believes an MRS facility would promote timely disposal of waste by providing siting and licensing experience transferable to the repository program. The repository program may benefit from siting an MRS facility to some degree, especially if another repository site must be found. The technical issues associated with siting an MRS are different than the technical issues involved in siting the repository. However, DOE experience in negotiating with a potential host State over permissible site investigation activities for an MRS and negotiating a benefits agreement with a potential MRS host State could prove useful should similar efforts be required in the repository program. This experience could be useful whether the MRS is sited by DOE or by the Negotiator.

The repository program is less likely to benefit from DOE experience in licensing an MRS than it would from siting one. Although some benefits through institutional experience in a structured licensing process could be obtained if the MRS is licensed in advance of the repository, licensing the repository will be different than licensing an MRS facility. The storage-only MRS currently favored by DOE relies on known technology and is a relatively simple, passive system. The repository is a far more complex facility. Its licensing will depend upon resolution of geologic uncertainties and will be dominated by questions such as, "What will happen to spent fuel many centuries after the repository is sealed?" The repository licensing regulations are, therefore, quite different from those that apply to an MRS facility.

Any institutional experience from siting and licensing a repository would be significantly reduced if the schedules for siting and licensing of the repository and the MRS overlap, as would be the case under the current statutory schedule linkages.

The Commission finds institutional experience in siting and licensing an MRS could be beneficial in the repository program, but would be less beneficial if the schedules overlap as they would under the current statutory linkages.

2. Timely Waste Acceptance

DOE ascribes four specific benefits to timely and adequate waste acceptance: avoidance of additional at-reactor storage; reduction in impact on reactor operations; avoidance of delays in decommissioning; and enhancement of compatibility with the waste management system.

a. Avoidance of Additional At-reactor Storage

Under the Nuclear Waste Policy Act, DOE has signed contracts with nuclear utilities which state that DOE is to accept title to the spent fuel, transport it, and dispose of it in a repository. The contracts specify that these services are to "begin, after commencement of facility operations, not later than January 31, 1998, and shall continue" until all spent fuel is disposed of.[6] The Nuclear Waste Policy Act of 1982 required the January 31, 1998, date to be included in the contracts in exchange for the payment of a 1 mill per net kilowatt hour fee to be paid by the utilities. Therefore, DOE wants to accept waste as early as possible to initiate fulfillment of the Federal responsibility to remove spent fuel from the reactor sites.

The Commission has not sought to determine the precise nature of DOE's legal obligation under the contract. Rather, it has assumed the statute and the contracts created the expectation that DOE would begin accepting title to the spent fuel, remove it from the reactor sites as soon as practicable after January 31, 1998, and continue to accept the waste on a reliable schedule until all of it is placed in a Federal repository.

The repository currently is scheduled to begin operation in the year 2003.[7] Unless an MRS can be available sooner, DOE will not be able to begin accepting waste by 1998. The Nuclear Waste Policy Amendments Act (NWPAA), however, links MRS development to the repository schedule; DOE cannot begin constructing an MRS until the Nuclear Regulatory Commission (NRC) authorizes repository construction, which is not expected until 1998.[8] Assuming MRS construction would take at least two years, a linked MRS could begin accepting waste in the year 2000 at the earliest. Repository schedule delays would further postpone construction of a linked MRS and, thus, delay the date when DOE will accept spent fuel.

DOE believes that if the statutory linkages to the repository schedule are removed, an MRS can be operable by 1998.[9] This belief assumes that the Negotiator will find a site for an unlinked MRS and that licensing and construction will not be delayed by technical or political difficulties. If these assumptions prove valid, DOE could begin accepting waste at an unlinked MRS in 1998.

Early acceptance of spent fuel at a repository or an MRS provides significant benefits to the utilities by reducing their need to expand storage capacity at reactors.

The economic benefit to the utilities of an unlinked MRS, in comparison to the No-MRS alternative, would increase if the repository were delayed. For example, an unlinked (or linked) MRS in the year 2000 with the repository in 2003 would reduce by about 4,000 MTU the need for storage at reactors and by 12 the number of reactors requiring additional storage.[10] (For this scenario the numbers are the same for the linked and unlinked cases.) If the repository were delayed until the year 2013, an unlinked MRS available in the year 2000 would eliminate the need for about 17,000 MTU of dry storage and would reduce the number of sites requiring dry storage from 62 to 34, a dif-

Table 8.1—Reduction in Dry At-reactor Storage Needs with an MRS For Selected Repository Start Dates[a]

Cases	Maximum MTU In Dry Storage	Difference From No-MRS Case	Maximum Number of Sites Requiring Dry Storage	Difference from No-MRS Case
Repository Opens in 2003				
No-MRS	7,693	—	43	—
Linked MRS[b] (2000)	3,562	4,131	31	12
Unlinked MRS[c] (2000)	3,562	4,131	31	12
Repository Opens in 2013				
No-MRS	20,878	—	62	—
Linked MRS[b] (2010)	14,475	6,403	58	4
Unlinked MRS[c] (2000)	3,750	17,128	34	28
Repository Opens in 2023				
No-MRS	28,354	—	65	—
Linked MRS[b] (2020)	27,114	1,240	65	0
Unlinked MRS[c] (2000)	3,750	24,604	34	31

[a]Source: Generated by WACUM simulator. Accuracy to five significant figures should not be implied. See Appendix G for acceptance schedules.
[b]Linked as specified in Nuclear Waste Policy Amendments Act of 1987.
[c]No schedule or capacity linkages.

ference of 28. These and other examples are summarized in Table 8.1.[11]

The schedule and capacity limits in the current law reduce substantially the benefits of early acceptance. DOE can only accept spent fuel at an MRS under the current linkages until the capacity limits specified in the NWPAA are reached. The statute limits the amount of waste at an MRS to 10,000 MTU until the repository begins to accept waste and to 15,000 MTU at any one time. As can be seen in Table 8.1, if the repository is delayed to 2013, a linked MRS would only reduce the number of MTU in dry storage by 6,000 MTU compared to about 17,000 MTU for an unlinked MRS, and would reduce the number of sites requiring dry storage from 62 to 58, a difference of 4, compared to a difference of 28 for an unlinked MRS. Thus, in the event the repository is delayed to 2013, the benefits of early acceptance would be significantly reduced by an MRS limited by the current capacity limits even if there were no schedule linkages. Far fewer utilities would benefit from such an MRS.

The Commission finds building an MRS linked to the repository schedule would not allow DOE to accept spent fuel by 1998, and utilities would be required to expand at-reactor storage. An unlinked MRS, however, could allow DOE to begin to accept spent fuel at an earlier date than a linked MRS and could reduce utilities' needs for additional at-reactor storage.

b. Interference with Reactor Operations

DOE believes the earlier the Federal government begins to accept waste, the less likely at-reactor storage could interfere with reactor operations. While this may be true, the Commission has not found that interference with reactor operations has been a significant problem to date. The utilities have been routinely handling spent fuel and storing it on-site in spent fuel pools for many years without difficulty. It is likely they can continue to do so in the future. Technology for dry storage has been developed and is being used at two sites and its use is expected to increase in the future. The NRC believes dry storage can be done safely. The Nuclear Regulatory Commission has stated spent fuel can be stored safely on-site throughout the operating life of a facility, and for at least 30 years following reactor shutdown, even assuming a 30-year extension of the original license.[12]

It is possible, however, that some utilities will be unable to store spent fuel on-site in dry storage because of technical obstacles (such as lack of suitable land) or institutional problems associated with obtaining licenses for additional on-site storage.[13] Repeated delays in the repository program and mounting spent fuel inventories at reactor sites could result in resistance to utility efforts to expand on-site storage capacity. At some point, opposition to continued on-site storage could disrupt the orderly operation of some reactors.

It is also possible to postulate situations in which it would be desirable, as a result of an operational emergency, to remove spent fuel from a reactor site. For example, an accident at a nuclear power plant could make it advantageous to have the plant's spent fuel pool available to assist with decontamination of the reactor and to store debris. It would be desirable to have a facility available to accept spent fuel in the event of such an emergency and also to prevent the shut down of otherwise satisfactorily operating nuclear power plants because of lack of storage capacity for spent fuel.

Possible interference with reactor operations was addressed in 1982 when the Nuclear Waste Policy Act was being developed. To prevent the disruption of reactor operations by the inability to provide on-site storage, Congress provided for limited Federal interim storage to "...prevent disruptions in the orderly operation of any civilian nuclear power reactor that cannot reasonably provide adequate spent nuclear fuel storage capacity at the site of such reactor when needed."[14] The Federal government was authorized to provide up to 1,900 MTU of Federal interim storage to be funded by user fees collected from the utilities that sought to use the facilities. The utilities were required to identify the need for such facilities by January 1, 1990.

No utility has indicated an interest in obtaining such services and the opportunity to do so is to expire at the end of 1989. One possible reason no utility expressed an interest in Federal interim storage is that situations of the sort contemplated by the statute in which the utility cannot provide on-site storage are difficult to predict in advance. In addition, problems are more likely to surface as more reactors run out of pool storage capacity. Only a few reactors were expected to do so before January 1, 1990. Furthermore, the statute as written did not provide backup storage for operational emergencies on-site or for unexpected reactor shutdowns that were not related to expanding on-site storage capacity.

An unlinked MRS could provide this backup capability. A linked MRS, which would be available later than an unlinked MRS, could provide the same backup capability but would not be available until about three years before the repository. The longer the repository is delayed, the longer the availability of the backup capacity would be delayed.

The Commission finds the difficulty in providing sufficient on-site storage could, in some instances, interfere with reactor operations. An MRS could serve as a backup facility in such instances and could be useful

during emergencies that require expeditious removal of spent fuel from reactor pools. These benefits could be provided by a linked MRS but, under current law, a linked MRS would not be available until three years before the repository is scheduled to begin to accept waste.

c. Decommissioning Delays

DOE asserts that early waste acceptance could prevent delays in decommissioning by relieving the need to store spent fuel on-site. DOE does not elaborate on this argument, but the Commission has examined this argument in some detail.

Decommissioning activities are covered by the NRC's regulations for the licensing of nuclear power plants.[15] Decommissioning cannot be completed until all spent fuel is removed from the site and the site is decontaminated.[16] However, under DOE's current contracts, spent fuel will not be transported off-site until at least five years after it is discharged from the reactor. The NRC's decommissioning regulations provide two options: (1) after the spent fuel is removed from the site, the facility and equipment can be decontaminated to a level that permits release of the property for unrestricted use shortly after reactor operations cease; or (2) after the fuel is removed from the reactor's pressure vessel, the facility can be maintained in a condition that allows safe storage for up to 60 years following reactor shutdown and then decontaminated and decommissioned. Some utilities may choose the second option because it allows the radioactive contaminants to decay prior to decommissioning and thereby reduces both the amount of radioactive waste to be disposed of and the occupational exposures during decontamination and dismantling. If a utility chooses the second option, failure to remove spent fuel from the site is unlikely to delay final decommissioning. If a utility chooses the first option, failure to remove the spent fuel within five years could delay decommissioning.

However, failure to remove the spent fuel from the site after reactor shutdown is not without consequence, even if the utility elects to defer final decommissioning. After a reactor shuts down and the NRC converts the facility operating license to a possession-only license, the extensive crew of licensed reactor operators, health physicists, and managers will no longer be needed to manage the reactor. The trained and experienced crew will likely disband and only the minimum number of personnel required to maintain the pool and site security will remain. Although the licensing requirements are less stringent after shutdown than during operations, they are more stringent and costly to implement than if the fuel has been removed from the site. Maintaining spent fuel at a reactor after shutdown is expected to cost between $2 million to $3 million more per site per year than if all spent fuel were removed.[17]

The staff at an MRS—trained and experienced fuel handlers, health physicists, and security staff—would be available at all times to manage the spent fuel. Providing the necessary personnel at a single site rather than at individual utilities would be more efficient and would result in cost savings to the utilities and ratepayers. Workers at an MRS will be better equipped to perform the routine spent fuel handling operations that would occur only infrequently at a shutdown reactor and they would be more able to handle emergencies that might occur.

As Figure 8.1 shows, only a limited amount—about 1,200 MTU—of storage capacity at a central facility would be required to take care of spent fuel five years old or older from shutdown reactors at sites with no other operating reactors until the year 2010.

The Commission finds that although spent fuel can be safely stored at reactor sites after reactor shutdown, there is some benefit to providing a central storage facility for spent fuel from shutdown reactors.

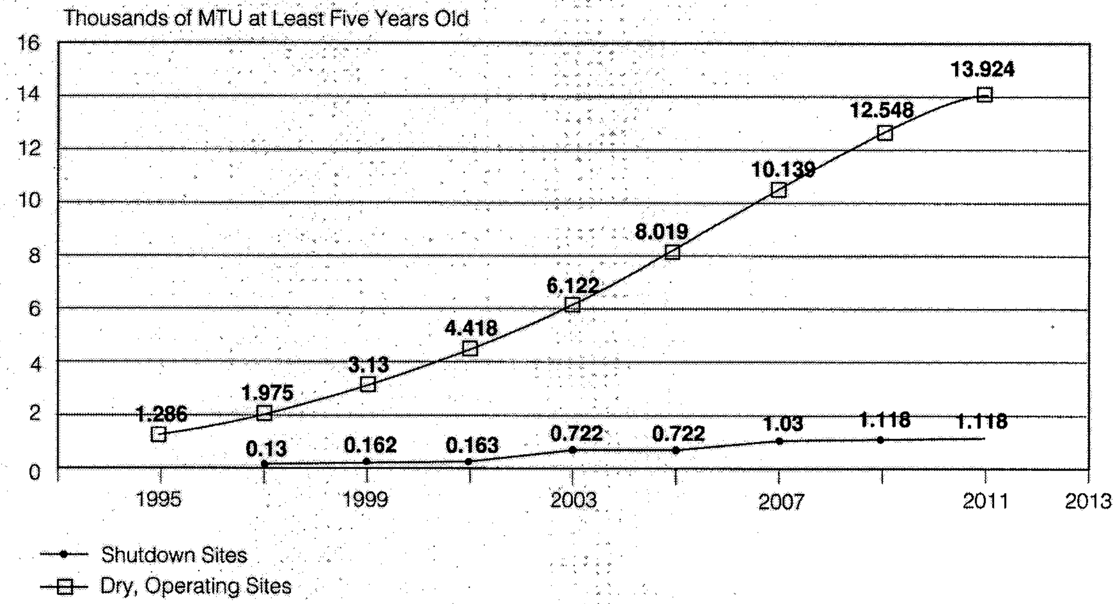
d. Improved System Compatibility

According to DOE, early acceptance of the waste also promotes greater standardization in the Federal waste management system. Standardizing spent fuel forms and waste package types would facilitate transportation and handling, reduce costs, and increase reliability. Conversely, the proliferation of waste forms and packages could increase total costs and reduce the reliability of the waste management system.

Unless a standardized storage form or package is required by DOE or NRC, utilities will respond to their interim storage needs on an individual, cost-effective basis. Some may consolidate; others may opt for dry storage using a variety of available technologies. Spent fuel currently is stored in two different types of dry storage facilities (metal casks and concrete bunkers) and several utilities are actively exploring options for additional types of dry spent fuel storage. (For example, Duke Power Company has submitted to the NRC a license application for a concrete bunker type of storage facility that will hold 24 pressurized water reactor (PWR) assemblies in each canister. DOE does not currently have a transportation cask that will handle such a large canister.)

Contracts between DOE and the utilities include specifications for "standard fuel." Fuel that has been consolidated or that exceeds certain limits for length and cross-section dimensions is considered "nonstandard" under the contract specifications.[18] Though obligated to accept nonstandard spent fuel, DOE may accept nonstandard fuel on a

Figure 8.1—Spent Fuel in Dry Storage and at Shutdown Sites without MRS or Repository



Source: WACUM Simulator

different schedule than standard fuel.[19] DOE also may require utilities to repackage nonstandard spent fuel in a package compatible with DOE's transportation system. If the utilities are not required to repackage, DOE will have to provide a fleet of transportation casks capable of handling consolidated and unconsolidated fuel and a wide variety of packages.

Standardization of the waste management system could be improved in at least three ways:

(1) DOE or NRC could specify standard requirements for the waste form or package that will be accepted from the utilities to fit the shipping casks that will be used for transportation.

(2) DOE could develop and provide to the utilities, or require utilities to purchase, a fleet of standardized dual-purpose casks and develop a transportation system to accommodate them as the Tennessee studies suggest.[20]

(3) An MRS could be built early, thereby reducing the number of utilities that will need to provide additional at-reactor storage with a variety of fuel forms and packages.

Before DOE or NRC can specify either the waste form (consolidated or unconsolidated) or the package that should be adopted, several technical questions need to be answered:

(1) In what geologic medium will the waste be placed

for disposal? (This is necessary to describe the final disposal package and to determine whether rod consolidation would be desirable with regard to repository loading or to minimize the number of waste packages.)

(2) What constitutes an optimum transport cask for rail and for truck?

(3) Will an economically viable dual-purpose cask be developed and made available in the near future?

Until these questions are answered, it is unlikely either DOE or NRC can specify a preferred waste form or package. These questions are not likely to be answered soon.

Having a family of standardized dual-purpose casks available early would enhance standardization. Whether a dual-purpose cask can be designed and licensed within a reasonable time remains to be seen, and the effects of having non-standardized waste forms or packages will be felt on transportation from the reactor either to an MRS or a repository. These effects will increase the longer DOE delays taking the spent fuel from the utilities.

Whether an MRS could be made available early is also uncertain. However, if an MRS were available in 1998, it is likely DOE would have less variety of spent fuel forms and packages than if one were to be available at a later date.

The Commission finds that if standardization is not mandated by the Federal government, an MRS facility that accepts waste early could promote standardization by reducing the variety of spent fuel forms and packages to be handled and could limit the number of reactors providing storage for other than intact, unpackaged spent fuel.

3. Schedule Confidence

DOE asserts that a Federal commitment to proceed with an MRS would increase confidence that the Federal government is using all available means to ensure timely assumption of its responsibility to accept spent fuel for disposal. To achieve this schedule confidence, the DOE wants to demonstrate the government's ability to accept and handle large quantities of spent fuel at high annual rates. The Commission agrees this is one way to increase confidence in the waste management program but suggests another way is for DOE to demonstrate progress towards developing a repository. These two means of achieving confidence are not incompatible as long as the MRS does not divert DOE's resources from the repository program. If the MRS could be built and licensed in advance of repository construction and licensing, it would be unlikely to divert DOE resources from the repository program and could enhance confidence that the Federal government is using all available means to ensure timely assumption of its responsibility to accept spent fuel for disposal.

If, however, the MRS schedule is linked to that of the repository, the MRS could be delayed and its schedule will be subject to the same uncertainties as the repository schedule. It is also more likely that the MRS could divert resources from the repository program if DOE attempts to site, construct, and license the facilities simultaneously as it would be required to do under the existing schedule linkages. Thus, a linked MRS will not serve to increase schedule confidence.

Uncertainties about DOE's ability to site an MRS within a reasonable time also must be considered. Siting any waste management facility in the United States provokes controversy. An MRS siting process could be protracted and traumatic and could divert DOE's attention from the repository program. If efforts to site an MRS facility became bogged down in controversy, then confidence in DOE's ability to manage the repository program could also be questioned. These problems could be reduced to some degree if the Nuclear Waste Negotiator sited the MRS. Controversy also may be reduced if MRS functions and schedule were constrained in such a way as to dispel the public's fears the site would become a de facto repository. However, these concerns about siting an MRS make the MRS schedule almost as uncertain as the repository schedule and severely limit any benefits associated with schedule confidence.

The Commission finds an MRS facility would assist utilities to plan for waste disposal if an MRS would be available by a certain date. However, concerns about siting an MRS make the MRS schedule almost as uncertain as the repository schedule and severely limit any benefits associated with schedule confidence.

4. Flexibility

DOE advocates the need for flexibility in the nuclear waste system during the development and operation of the repository. According to DOE, an MRS facility would help stabilize the waste program by relieving pressure on the repository program to meet specific deadlines. Unexpected difficulties could then be resolved during the site characterization process without the pressure of time deadlines. If a more deliberative approach were taken to building the repository, then DOE would have more time to take a sound scientific approach towards resolving technical uncertainties.

Many of the DOE's arguments in support of putting flexibility in the system attempt to build redundancy into the system to prevent a "worst case scenario." From an engineering perspective, redundancy in designing such a system is essential to prepare for the unexpected and unforeseen. Storing spent fuel in a central location would provide redundancy by providing surge capacity before and after the repository is in operation. An MRS facility might also supplement repository operations by simplifying waste preparation and transport. This could be beneficial, particularly if the repository were significantly delayed.

The Commission finds that an MRS facility would provide overall system backup to repository operations. However, this flexibility would be significantly reduced by the current statutory linkages because the MRS would not be available until shortly before the repository is available.

C. Tennessee Studies on the Need for an MRS Facility

The State of Tennessee maintains an MRS facility is not needed and is too expensive; Tennessee advocates an Integrated No-MRS (I-No-MRS) system. According to the State, an Integrated No-MRS system "is by far the most preferred system, taking into account all public policy issues, including technical feasibility, institutional feasibility, cost, risks and impacts."[21]

Tennessee's concept of an Integrated No-MRS originated in response to the Department of Energy's 1985 proposal to build an MRS facility near Oak Ridge, Tennessee. Tennessee's concept is based on previous studies performed in 1985 and 1986 evaluating DOE's proposal and on two recent studies performed by the University of Tennessee.[22] It also draws on the position that the Tennessee Valley Authority presented to the Commission during public hearings held on January 17, 1989. The I-No-MRS system relies on dual-purpose casks to store spent fuel at reactor sites; transport spent fuel to the repository; and provide buffer storage at the repository until the waste can be packaged and emplaced for disposal. One of the Tennessee studies suggests the casks could be purchased by DOE and leased to the utilities.[23] Tennessee urges DOE to work with utilities to upgrade their cask handling facilities to accommodate dual-purpose casks with as large a capacity as possible, and Tennessee asserts that, if the technology proves feasible, utilities might consider on-site consolidation of spent fuel to further increase cask capacities. Under the I-No-MRS system, spent fuel from the reactor sites would be shipped almost entirely by rail. For reactors without direct rail access, the spent fuel would be shipped by barge or heavy haul truck to the nearest railhead.

The State and its supporting studies contend a system without an MRS facility has numerous advantages: (1) deleterious transportation effects are minimized based on an evaluation of four proxy measures: number of casks shipped, trip-miles, ton-miles, and cask-days;[24] (2) a comparison of nominal system costs (of the I-No-MRS, DOE's No-MRS, and DOE's Integrated or I-MRS system) revealed dramatic cost savings with the I-No-MRS system;[25] (3) an I-No-MRS system provides great flexibility in the waste management system because managing spent fuel safely would not be dependent on meeting the repository schedule or keeping the repository open;[26] (4) the focus of the program would remain on the primary goal of deep geologic disposal of nuclear waste if an MRS facility were not built;[27] (5) reliability in the system would be retained without an MRS facility. If an integral MRS facility were built and all the pools at reactors were filled, any problem in the system—shipment failures, equipment malfunctions, safety questions, licensing difficulties—would bring the system to a "screeching halt";[28] (6) principal reliance on at-reactor storage, with Federal interim storage available if utilities need it, is consistent with the Nuclear Waste Policy Act of 1982.[29]

The State of Tennessee does not support an MRS but urges a number of requirements be mandated in law if the MRS Review Commission recommends an MRS facility be built. The State wants a negotiated siting approach, whereby the MRS is located in a State if and only if the host State finds it acceptable and agrees through a signed and legally enforceable agreement with the Federal government. Tennessee also advocates that any MRS should be user-funded—that is, paid for only by the utilities that use it. Last, the State recommends retaining the statutory linkages in the Nuclear Waste Policy Amendments Act of 1987.[30]

D. MRS Review Commission's Analysis of Tennessee Studies

The State of Tennessee draws on a variety of studies and the views of the Tennessee Valley Authority to build its case against an MRS facility. The Commission believes Tennessee makes a number of valid arguments. However, there are some important weaknesses in Tennessee's arguments, as there were in DOE's.

Tennessee's proposed I-No-MRS system relies in large part on the development and use of dual-purpose casks. Certain assumptions are made about their availability and costs. As the analysis in Chapter Four indicates, such casks may become available in the next few years, but there are uncertainties regarding when they will become available and whether they will eliminate the need for extra handling of the spent fuel. If an economical cask were developed that could be used for transportation after a period of prolonged storage without the need to reopen the cask or handle the spent fuel, it would provide many benefits to the waste management system. Whether or when such a cask

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providing all of the postulated benefits would be available is uncertain.

1. Transportation Impacts

The State believes the transportation impacts of the I-No-MRS system would be less than an MRS system according to four proxy measures: number of casks shipped; trip-miles; ton-miles; and cask-days. The reason the I-No-MRS system shows less impacts with regard to these proxy measures is because the Tennessee studies assume large cask capacities, and that 87 percent of all spent fuel shipments from the reactors will be by rail. (See Chapter Five.)

Even though the Commission has found that the risks from transportation of spent fuel are expected to be small, whether or not an MRS is built, these risks are perceived by many to be quite large. Therefore, improvements in the transportation system from the reactors that could reduce the numbers of shipments and people affected by the shipments might be beneficial with or without an MRS in the system. The Commission agrees that DOE should explore ways of increasing the efficiency of the transportation system from the reactors to the extent practicable and economically justifiable. As Tennessee recognizes, DOE is gathering data on cask handling and transportation capabilities in its Facility Interface Capability Assessment (FICA) that will enable it to explore these options. However, whether the transportation system from the reactors could or should be upgraded to the extent postulated by Tennessee remains to be seen.

Even if the changes recommended by Tennessee were possible, transportation impacts alone do not justify acceptance or rejection of an MRS. As the analysis in Chapter Five shows, radiological and non-radiological risks associated with the various transportation alternatives are small and within regulatory limits under all of the options evaluated. Thus, transportation risk does not provide a basis for choosing between the No-MRS and MRS alternatives.

2. System Costs and Financing

The principal differences in cost between the University of Tennessee study and DOE's studies are attributable to Tennessee's assumptions of major cost increases, similar to those observed with other nuclear facilities, for the MRS and repository in the waste management system, and favorable assumptions regarding the costs of activities performed at reactors, including dual-purpose cask costs. DOE's studies rely on engineering estimates of the costs of these activities which are generally lower than Tennessee's probabilistic estimates. This Commission's analysis used a methodology and cost assumptions that were similar to Tennessee's and, at least in the early years, show the No-MRS system to be substantially less expensive than the MRS system. However, the Commission's analysis shows that if there were extensive delays in opening the repository, and if the costs of delaying the removal of spent fuel from shutdown reactors were included as a component of total system costs, systems that include an unlinked MRS (if available early) would have a lower undiscounted net cost than waste systems that do not. If costs were discounted and expressed as present value, the No-MRS system would retain its cost advantage, but the advantage would narrow if the repository were delayed to 2023.

There are great uncertainties associated with all of the cost estimates, but the cost differences between the MRS and No-MRS options are likely to be less than the Tennessee studies indicated. More importantly, these uncertainties in the cost estimates make it difficult and perhaps unwise to use cost as the sole or primary reason for determining the need for an MRS.

As described more fully in Chapter Seven, the Commission agrees with the State of Tennessee's arguments that if an MRS is built, it would be more equitable if the costs attributable to the MRS were borne by the utilities using the facility. In this way, there will be a better correlation between ratepayers who actually benefit from the facility and those who will pay the associated costs. Furthermore, a user-fee system would be more efficient because it would encourage utilities to choose the most efficient storage alternative.

3. System Flexibility

Tennessee asserts the Integrated-No-MRS system provides great flexibility in the waste management system because managing spent fuel safely would not be dependent on meeting the repository schedule or keeping the repository open. Tennessee believes at-reactor storage would not affect reactor operations or delay decommissioning. According to the Tennessee studies, spent fuel could be safely stored in dual-purpose casks at the reactors until the repository is available to accept the waste.[31] Spent fuel pools could be dismantled after reactor shutdown because the casks could be transported without returning them to the pools.[32] Hoskins asserts that if it were desirable to move all spent fuel from the sites of shutdown reactors, the dual-purpose casks could be moved to an MRS and stored there until a repository was available.[33] However, according to Hoskins, this would not be necessary, unless the repository is delayed beyond the year 2020 when decommissioning could become a pressing problem. He also asserts that it is unnecessary to make a decision on whether this type of MRS is needed until after the year 2000 when better information on the prospects for repository operation will be available.[34] The Tennessee studies suggest dual-purpose casks could also be used for buffer storage at the repository to provide flexibility in packaging operations and decouple shipments from the reactors from possible disruptions in repository operations.[35]

If the Commission were certain that a dual-purpose cask could be developed that could be used for prolonged storage and then transported without having to be returned to a spent fuel pool or opened, then it might conclude that the I-No-MRS system would provide a great deal of flexibility. However, it is not clear that such a cask can or will be developed. In any event, it is not prudent to drain the spent fuel pools while fuel remains on-site. If a cask developed a problem and it became necessary to transfer the spent fuel to another cask, the pool would be needed. Therefore, a waste management system with an MRS which would allow removal of the spent fuel from the sites would be more flexible than the No-MRS option.

4. De Facto Repository and the Need for Linkages

The State of Tennessee and the Tennessee Valley Authority, among others, assert that the Nation's focus should remain on the primary goal of deep geologic disposal. Hoskins states that the I-No-MRS system favors scheduling disposal at the earliest possible time because it keeps the pressure on DOE, the utilities, and everyone involved to press on with the repository program. It also avoids the distraction and diversion of resources from the repository program.[36] In its Final Comments to the Commission, Tennessee states, "Moreover, Tennessee would consider interim storage at an MRS as an indication that DOE is not effectively dealing with the disposal problem and that such actions are a prelude for allowing the MRS to become a defacto [sic] repository."[37] Tennessee asserts that the linkages were included in the NWPAA to ensure that building the MRS would not reduce the Federal government's commitment to developing a permanent repository.[38] According to Tennessee, the linkages were made especially stringent to compensate for the fact that the repository program was focused on characterizing a single site rather than three sites.[39]

The Commission disagrees that interim storage at an MRS would be an indication that DOE is not effectively dealing with the disposal problem. One of Tennessee's own studies recognizes "a considerable period of time will be necessary to evaluate a repository site, and that a more experimental, evolutionary, flexible, and cheaper approach to site investigation, with less pressure from a rigid schedule, would be beneficial and, perhaps, avoid a perceived failure of the program in the mid-1990s."[40] Dr. E. William Colglazier, the author of the study, supports the I-No-MRS option, but he also states,

> Even though it is technically feasible and cost effective to store on-site at reactors for the foreseeable future, as assumed in the Integrated No-MRS case, the pressure for government acceptance of utility spent fuel may increase in the 1990's, especially if the repository program begins to falter. This pressure for early federal acceptance of spent fuel is one of the reasons for the rigid repository development schedule in the NWPA. How to deal with this pressure is, for me, one of the major problems with the Integrated No-MRS option.[41]

The Commission agrees a balance must be struck between providing enough flexibility for a sound repository development schedule and maintaining sufficient pressure to move forward with the repository program. The existing linkages, particularly those that tie the MRS schedule to that of the repository, keep pressure on the repository program but severely limit the flexibility of the waste management system.

The State of Tennessee asserted that progress on the MRS should remain linked to the repository schedule as mandated in the NWPAA. As the foregoing analysis of DOE's postulated benefits shows, the existing statutory linkages significantly reduce the benefits associated with an MRS. However, the Commission observes that Congress, for many years, has also expressed concern that an unlinked MRS might be regarded as a de facto repository and could reduce the impetus for proceeding with permanent geologic disposal. The Commission recognizes this expression of congressional will, Tennessee's sentiments, and the concerns others voiced during the Commission's hearings.

Although the Commission does not believe there is a technical basis for the linkages, the Commission finds that, in light of congressional and other concerns, some linkages are justified.

5. System Reliability

Tennessee asserts the I-No-MRS system is more reliable than the MRS system. The State argues that once spent fuel pools at the reactors are filled, the breaking of any link in the MRS chain—shipment to the MRS, equipment malfunction, safety questions, licensing difficulties—could bring the waste management system, and eventually nuclear plants, to a halt.[42] Hoskins and Colglazier strongly criticize the MRS option because the controversy over siting and licensing an MRS makes its availability uncertain.[43] Colglazier questions whether Congress would be willing to impose an MRS on a State considering his view that an MRS is not absolutely necessary.[44]

The Commission agrees that if all spent fuel is to be shipped through an MRS, it could indeed become a bottleneck in the system if a disruption in its operations were to occur. Furthermore, the ability to site an MRS successfully is far from assured. However, if an MRS were to be used as a storage-only facility through which only some spent fuel would flow, it would be less likely to become the bottleneck Tennessee suggests.

Furthermore, the No-MRS option is also somewhat unreliable. Whether utilities will be able to expand on-site storage capacity in all cases is questionable. Having a backup storage facility in the system would provide redundancy that could be useful either to remove the spent fuel from the sites or to prevent disruptions in the orderly operation of reactors if utilities were unable to expand their on-site storage facilities.

6. Intent of Congress

Tennessee asserts that principal reliance on at-reactor storage until a repository becomes available, with Federal interim storage available if utilities need it, is consistent with the Nuclear Waste Policy Act of 1982. As Tennessee indicates, interim storage of spent fuel at reactor sites and the provision of 1,900 MTU storage capacity by the Federal government is consistent with the NWPA. However, the ability to apply for Federal interim storage expires on January 1, 1990 and the statutory scheme in the Nuclear Waste Policy Act was premised on the expectation that a repository would be available to accept spent fuel by January 31, 1998.

In the 1987 amendments to the Nuclear Waste Policy Act, Congress authorized an MRS and created this Commission to determine whether an MRS should be built. Therefore, the Commission cannot determine from the Nuclear Waste Policy Act, as amended, a clear congressional intent to rely solely on at-reactor storage, particularly if the repository is significantly delayed.

Tennessee criticizes DOE for elevating early spent fuel acceptance by the government to an equal or superior role to that of disposal in its mission, and asserts this policy is contrary to the NWPA, as amended.[45] Tennessee claims that DOE uses the MRS to provide increased confidence in the government's ability to accept spent fuel from the utilities on a timely basis when the only step that will build confidence in the DOE program is orderly progress in development of the repository. Tennessee states, "DOE's analysis appears to be positioning the MRS to accommodate an extended delay in the repository program, which would decrease rather than increase confidence in the program."[46] As the Commission stated in Part B.1 of this section, both early acceptance of spent fuel and demonstrating progress towards disposal of spent fuel would enhance confidence in the waste management program and these two means of achieving confidence are not necessarily incompatible.

7. A Negotiated Approach

The Commission agrees that a negotiated approach is preferable since, according to the NWPAA, such an approach would directly involve the State or Indian Tribe in delineating the terms and conditions under which an MRS would be acceptable, and would preserve the State or Indian Tribe's right to disapprove. However, if it is determined that an MRS would provide significant benefits, the option of DOE siting should be preserved.

Section Two: MRS Review Commission's Summary of Advantages and Disadvantages of an MRS

After reviewing the extensive work undertaken by the Department of Energy and the State of Tennessee, other views expressed to the Commission, and the Commission's own studies, the Commission summarized the following advantages and disadvantages of having an MRS:

A. Advantages

The most important advantages that could be realized by building an MRS facility are:

1. An MRS could serve as a backup facility to prevent situations in which inability to expand on-site storage could interfere with reactor operations or to handle operational emergencies that require expeditious removal of the spent fuel from the reactor pool.
2. An MRS facility would provide for timely removal of spent fuel from decommissioned reactors. Although the waste could be stored at reactor sites safely for up to 100 years, the fuel could be stored more efficiently and safely at a central facility.
3. An MRS facility would provide overall system backup to repository operations. From an engineering perspective, redundancy in designing such a system is essential in the event the unexpected and

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unforeseen happens. An MRS facility would provide surge capacity before and after the repository opens.

4. Utility requirements for on-site storage after 1998 would be reduced and fulfillment of the Federal responsibility to begin to remove spent fuel from the reactor sites would be initiated at the earliest possible time.
5. Institutional experience in siting and licensing an MRS could be beneficial to the repository program.
6. If standardization is not mandated by the Federal government, then an MRS facility that accepts waste early could promote standardization by reducing the variety of spent fuel forms and packages to be handled and limiting the number of reactors providing storage for other than intact, unpackaged spent fuel.

The benefits of providing backup to on-site storage or for operational emergencies, surge capacity, early waste acceptance, institutional experience in siting and licensing, and standardization would be significantly reduced by the capacity and schedule linkages currently contained in the NWPA, as amended. The benefits of removing spent fuel from shutdown reactors would also be reduced by the linkages if the repository is delayed beyond 2013.

Some of the advantages of building an MRS facility enumerated above would be significantly reduced if the repository is available early. Institutional lessons learned in licensing an MRS facility would not be of much use to the repository program if the time frame for building both facilities overlapped. The overall cost advantages to the nuclear waste management system would diminish. The variety of spent fuel forms and packages to be handled by the waste management system would be less. The need to remove spent fuel from decommissioned reactors is small until after 2013.

B. Disadvantages

The major disadvantages in building an MRS are:

1. An MRS facility could divert the Nation's focus from deep geologic disposal and become, in effect, a de facto repository.
2. An MRS facility could divert Department of Energy resources from the repository program.
3. Siting an MRS facility is likely to be extremely difficult, no matter what its capacity limit or location.
4. An integral MRS facility through which all spent fuel must pass could create a bottleneck in the system that would disrupt reactor and repository operations.
5. Unless a repository were delayed beyond 2013 and an unlinked MRS were built at an early date, the cost of a system including an MRS would exceed the system cost of a No-MRS option.

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Drawing upon the quantitative analyses in Chapters Four through Seven and the qualitative analyses in Chapter Eight, the Commission's conclusions and recommendations are described in Chapter Nine.

Chapter Eight Notes

1. Department of Energy, System Studies, Tasks A-J; Isaacs, Thomas H., Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, "DOE's Position on the Monitored Retrievable Storage (MRS) Facility," Prepared Remarks, Briefing Before the Monitored Retrievable Storage Review Commission, May 25, 1989, **(Hereafter cited as Isaacs, Prepared Remarks)**; McWherter, Ned, Governor of the State of Tennessee, "Tennessee's Position on the MRS: Final Comments to the Monitored Retrievable Storage Review Commission by the State of Tennessee," July 1989 **(Hereafter cited as Tennessee's Final Comments)**; Colglazier, E. William, "Rethinking the MRS: Public Policy Issues Surrounding Monitored Retrievable Storage of Spent Nuclear Fuel—Final Report to the State of Tennessee," June 1989 **(Hereafter cited as Colglazier, Final Report)**; Hoskins, Raymond E., "A Systems Evaluation of the High-Level Waste Management System Based on Integration of Dual Purpose Cask into the System as an Alternative to DOE's Proposed Monitored Retrievable Storage Facility as an Integral Part of the System Final Report," June 1989 **(Hereafter cited as Hoskins, Final Report).**

2. DOE does not analyze cases in which the repository is delayed beyond the year 2013 and Tennessee's studies do not include scenarios extending beyond 2008.

3. Isaacs, Prepared Remarks, p. 9.

4. Isaacs, Prepared Remarks, pp. 11–12.

5. Isaacs, Prepared Remarks, p. 10.

6. 10 CFR 961.11, Article II.

7. Isaacs, Prepared Remarks, pp. 4, 8. Department of Energy, "Draft 1988 Mission Plan Amendment," DOE/RW-0187, June 1988 **(Hereafter cited as DOE/RW-0187)**, p. 15.

8. DOE/RW-0187, p. 15.

9. Isaacs, Prepared Remarks, p. 4.

10. These numbers were generated by the Nuclear **WA**ste Cost Data Base and Sim**U**lation **M**odel (WACUM). See Appendix G.

11. A recent study submitted to the Commission by the Edison Electric Institute shows similar effects. See Edison Electric Institute, Utility Nuclear Waste and Transportation Program, "An Evaluation of the Role of a Monitored Retrievable Storage Facility," August 1989.

12. Waste Confidence Decision Review, 54 FR 39767 (September 28, 1989). See also, Chapter Three, Note 20.

13. It cannot be said with certainty that every reactor can use dry storage to achieve life-of-plant storage.

14. 42 U.S.C. § 10151.

15. Nuclear Regulatory Commission, "General Requirements for Decommissioning Nuclear Facilities," 53 FR 24018 (June 27, 1988) **(Hereafter cited as 53 FR 24018).**

16. 53 FR 24018, 24019.

17. Pacific Northwest Laboratory, "MRS Systems Study Task G Report," PNL-6876, April 1989, p. 3.19.

18. 10 CFR 961.11, Appendix E.

19. 10 CFR 961.11, Article VI, Section A(2)(b).

20. Hoskins, Final Report, pp. IV–2 to IV–3 and IV–20 to IV–21.

21. Tennessee's Final Comments, p.1.

22. Colglazier, Final Report; Hoskins, Final Report.

23. Hoskins, Final Report, IV–38.

24. Tennessee's Final Comments, p. 6.

25. Tennessee's Final Comments, p. 6.

26. Hoskins, Final Report, pp. IV–23 to IV–24.

27. Tennessee's Final Comments, p. 6.

28. Tennessee's Final Comments, p. 5.

29. Tennessee's Final Comments, p. 5.

30. Tennessee's Final Comments, p. 15.

31. Hoskins, Final Report, pp. IV–21 to IV–26 and IV–35 to IV–39.

32. Hoskins, Final Report, pp. IV–23 and IV–25.

33. Hoskins, Final Report, pp. IV–21 and IV–23.

34. Hoskins, Final Report, p. IV–23.

35. Hoskins, Final Report, pp. IV–25 to IV–26.

36. Hoskins, Final Report, p. I–15.

37. Tennessee's Final Comments, p. 14.

38. Tennessee's Final Comments, p. 16.

39. Tennessee's Final Comments, p. 16.

40. Colglazier, Final Report, p. 4.

41. Colglazier, Final Report, p. 7.

42. Tennessee's Final Comments, p. 5.

43. Colglazier, Final Report, pp. 4–5, 6, 10; Hoskins, Final Report, pp. V–57 to V–58.

44. Colglazier, Final Report, pp. 4–5.

45. Tennessee's Final Comments, p. 13.

46. Tennessee's Final Comments, p. 14.

Chapter Nine
Conclusions and Recommendations

The issues assigned to the Monitored Retrievable Storage (MRS) Review Commission for study and recommendations encompass complex, contentious questions. Solutions to these problems are not susceptible to simple, unequivocal answers. Although there are many technical aspects to the questions, the responses require the application of judgment and policy considerations.

The Commission has attempted to address its mandate as objectively as possible and has considered the issues submitted to it in a broad perspective. The Commission's recommendations are intended to be consistent with the primary goal of the Nation's nuclear high-level radioactive waste disposal program: to construct and operate a geological repository as expeditiously as possible, consistent with meeting necessary safety and other public interest considerations.

The Commission has evaluated an MRS and other alternatives using at-reactor storage (No-MRS) as the basis for comparison. In doing its analyses, the Commission directed staff studies and was assisted by contractors. (See Appendix E.)

The Commission evaluated an MRS on the basis of whether its advantages would exceed its disadvantages. Although studies by the U.S. Department of Energy (DOE) and others have shown that an MRS is more expensive than a No-MRS case, the Commission does not believe that economics alone should be the deciding factor in determining whether there should be an MRS.

The Commission's task has been made more difficult by the many uncertainties that confront the national waste management program, especially the date when the repository will be in operation.

Although site characterization activities are now focused on Yucca Mountain, no site has been selected yet, and it is not known when a site will be designated and licensed. Delays have already occurred in the anticipated date for repository operation, and it is expected that further schedule slippage will occur. Thus, one of the most important factors driving the Commission's recommendations has been an attempt to mitigate any adverse effects on the Nation's nuclear waste management disposal program that might result from uncertainty with respect to the repository's date of operation.

Section One: Conclusions

In light of the Commission's studies and the considerations noted above, the Commission has reached five conclusions:

Conclusion No. 1. From a technical perspective, both the No-MRS and MRS options are safe.

Although neither option is completely without risk, the risks are expected to be small and within regulatory limits, and the degree of difference in risks between the No-MRS and MRS options is so small that the magnitude of difference should not affect the decision whether there should be an MRS.

Conclusion No. 2. The net cost of a waste management system that includes an MRS would be lower than previously estimated because of delays that have already occurred in the expected date of repository operation and the likelihood of further slippages of that date.

As Chapter Six noted, the economics of an MRS would become more favorable if the repository were delayed and the MRS were to accept fuel as early as possible. These economic effects would be especially significant if the repository operation were to be delayed beyond 2013, when there will be a sharp increase in the number of nuclear power plants whose current licenses will expire. If a repository were not accepting spent fuel by that time, utilities would incur major additional costs because they would be unable to remove spent fuel from plants being decommissioned. The possibility of further delay in the repository opening therefore places the economic benefits of an MRS in a different and more favorable light than previously reported.

If the repository were to be delayed to the year 2013, the undiscounted costs of a system without an MRS facility nevertheless would be slightly lower than those of a system that included an MRS available in the year 2000. If the costs were discounted and expressed as present values, assuming a 4 percent rate of discount, the No-MRS case would remain less expensive than the MRS case even if the repository were delayed to 2023. (See Chapter Six and Table 6.8.)

Conclusion No. 3. There are no single discriminating factors that would cause the MRS alternative to be chosen in preference to the No-MRS alternative.

However, the Commission finds that an MRS whose schedule of operation and capacity is not linked to the repository would serve the following purposes:

a. Supplying storage for emergencies, such as after a nuclear power plant accident, when it would be advantageous to have the plant's spent fuel pool available for decontamination of affected reactor parts and storage of debris.

b. Providing storage for utilities that have insufficient space in their spent fuel pool or on-site or that cannot obtain licenses for additional at-reactor storage, thus preventing the shut down of otherwise satisfactorily operating nuclear power plants.

c. Furnishing storage for spent fuel from shutdown reactors, especially at sites where utilities no longer operate nuclear power plants.

d. Creating economies in the waste management system if an MRS could be completed substantially in advance of the repository, especially if the repository were delayed beyond 2013 and an MRS were in operation by 2000.

e. Allowing greater redundancy in the system in the event of unforeseen circumstances.

f. Offering more surge capacity to facilitate the flow of spent fuel to the repository.

g. Providing more flexibility in storage options and future waste preparation functions.

h. Assisting in standardization.

i. Initiating Federal responsibility for taking possession of spent fuel.

None of these factors alone would warrant an MRS, but cumulatively they justify a facility not limited in capacity or linked to the repository schedule and operation.

Conclusion No. 4. An MRS linked as provided in current law would not be justified, especially in light of uncertainties in the completion time for the repository. Consequently, the Commission does not recommend a linked MRS as required by current law and as proposed by DOE.

For many years, Members of Congress have expressed concern that an unlinked MRS might be regarded as a de facto repository, thereby reducing the impetus for proceeding with permanent geologic disposal. The Commission acknowledges this expression of congressional will. During the Commission's public hearings, Members of Congress, congressional staff, environmental groups, and members of the public expressed concern that an MRS would become a de facto repository. Although the Commission does not believe there is a technical basis for the linkages, it agrees that, in light of congressional and other concerns about a de facto repository, some linkages are justified.

However, as Chapter Eight indicated, the schedule linkage presently in the law (MRS construction may not begin until the Nuclear Regulatory Commission (NRC) issues a license for the repository's construction) would make it impossible for an MRS to become operational more than three years before the repository. Because of delays already experienced in the scheduled repository opening and continued uncertainty surrounding the repository's location and date of operation, the value of the MRS would be greatly diminished if its construction were tied to the schedule of the repository. Most of the need for an MRS would have disappeared because utilities would have had to make other arrangements for storage.

As noted in Chapter Eight, the capacity and schedule linkages currently contained in the Nuclear Waste Policy Act (NWPA), as amended, would significantly reduce the benefits of providing backup to on-site storage or for operational emergencies, surge capacity, early waste acceptance, institutional experience in siting and licensing, and standardization. The benefits of removing spent fuel from shutdown reactors would also be reduced, especially if the repository opening were delayed beyond about 2013.

Conclusion No. 5. Some interim storage facilities, substantially more limited in capacity and built under different conditions than the DOE-proposed MRS, are in

the national interest to provide for emergencies and other contingencies.

The Commission recognizes the need to provide certain services that would be in the national interest, but that could not be provided by an MRS restricted by the schedule linkages currently in the law. The Commission concludes that spent fuel storage for emergency and other purposes and storage necessary to prevent utilities from shutting down otherwise satisfactorily operating nuclear power plants would be in the national interest. Facilities to fulfill this national interest could be more limited in scope and could be built under different conditions than the DOE-proposed MRS.

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The Commission was directed by Congress to compare the alternative of at-reactor storage of spent fuel to storage at an MRS facility, taking into consideration the impact on "repository design and construction; waste package design, fabrication and standardization; and waste preparation." (Section 143(a)(2)(A-C) of the Nuclear Waste Policy Act, as amended.) Because no repository site has yet been chosen or licensed, it was not possible to make findings on any of these three items since their consideration depends upon the host rock of the repository. However, the Commission's recommendations are structured so that they will foster such consideration and will not negatively impact on repository design and construction; waste package design, fabrication, and standardization; and waste preparation.

Section Two: Recommendations

In view of the above conclusions, and in consideration of Section 143(a)(1)(C)(iv) of the Nuclear Waste Policy Act, as amended, the Commission submits three recommendations for "improving the flexibility of the repository development schedule, and providing temporary storage of spent nuclear fuel accepted for disposal":

Recommendation No. 1. Congress should authorize construction of a Federal Emergency Storage (FES) facility with a capacity limit of 2,000 metric tons of uranium (MTU).

In light of the continuing delay in building a repository, the Commission believes it would be in the national interest to have available a safety net of storage capacity for emergency purposes, such as an accident at a nuclear power plant, which would make it advantageous to have the plant's spent fuel pool available for decontamination of affected reactor parts and for storage of debris.

If the facility proposed in Recommendation No. 2 were not available, the FES also could be used for storing spent fuel from otherwise satisfactorily operating nuclear power plants that would have to be shut down because of insufficient on-site storage.

Except for the fact that it would be used primarily for emergency purposes, the FES would be similar to the Federal Interim Storage (FIS) facility called for in Section 135 of the Nuclear Waste Policy Act of 1982. Likewise, limitations on using the FES for reactors facing imminent shutdown due to lack of storage facilities would be the same as those contained in Section 135(b) of the NWPA. However, construction of the FES would not be contingent on utilities meeting a deadline for contracting for use of the FES, as is presently provided for the FIS in Section 136(a) of the NWPA. The Commission believes that the FES should be constructed without reference to the NWPA deadline because the facility is needed primarily for emergencies, and emergencies, by their very nature, are unpredictable.

In locating the FES, consideration should be given to one or more Federal sites, where experience has already been gained in storing spent fuel or high-level nuclear waste. Selecting an existing Federal site would also facilitate construction and result in possible economies.

The Commission recommends that, consistent with NWPA provisions, an NRC license not be required if the FES is located at an existing Federal site. The NRC, however, should be asked to make a finding that using a Federal site for an FES would adequately protect public health and safety. The Commission further recommends that an NRC license be required if the FES is located at a non-Federal site.

A Commission contractor has estimated that the FES capital cost would range from about $300 million to $400 million. (See Appendix I, Section One.)

Because the FES would be designed primarily for emergency use and hence would serve as "insurance" for the entire nuclear power industry, the cost of the FES should be paid from the Nuclear Waste Fund, and, hence, shared by the entire industry. However, owners of reactors that were shut down because of lack of storage space should be required to pay for their use of the FES, since they would do so if the storage facility proposed in Recommendation No. 2 were operational.

Accidents at nuclear power plants that would shut down or require the shutdown of a reactor are not common, and, therefore, are difficult to predict. Likewise, it is impossible now to know how many utilities will have difficulty licensing additional at-reactor storage. The Commission believes that given its other recommendations, an FES capacity of 2,000 MTU would be adequate for the purposes indicated. The rationale for this limit is described in Appendix I, Section Two.

Recommendation No. 2. Congress should authorize construction of a User-Funded Interim Storage (UFIS) facility with a capacity limit of 5,000 MTU. Such a facility would provide storage only, and would be used in addition to the Federal Emergency Storage facility proposed in Recommendation No. 1.

Although spent fuel can be stored safely at reactor sites for as long as 100 years, some utilities may not have space at their reactor sites for life-of-plant storage or may not be able to obtain a license for additional storage.

In view of the uncertainties regarding the date of availability of a repository, it would not be in the national interest to force utilities to shut down otherwise satisfactorily operating nuclear power plants because they lack storage for spent fuel. Congress recognized this problem by authorizing, in Section 135 of the NWPA, a Federal Interim Storage facility. It is the Commission's intention that the 5,000 MTU storage facility recommended herein should also be available in such contingencies.

The UFIS facility also should provide storage for: (a) shutdown reactors at sites where a utility no longer operates nuclear power plants, and (b) utilities that would prefer to ship spent fuel to this facility rather than retain it on-site.

Although spent fuel can be stored safely on-site, the Commission believes there would be an added margin of safety in making storage available at a central facility for spent fuel from shutdown reactors of utilities that no longer operate other nuclear power plants at the same site.

As noted in Chapters Four and Eight, after a reactor shuts down, the extensive crew of licensed reactor operators, health physicists, and managers will no longer be needed. The trained and experienced crew will likely disband and only the minimum number of personnel required to maintain the pool and site security will remain. Moreover, maintaining spent fuel at a shutdown reactor is expected to cost $2 million to $3 million more per site per year than if all the spent fuel were removed.

A central interim storage facility would be advantageous in the circumstances described above because it would provide a group of trained and experienced fuel handlers, health physicists, and security staff available at all times. Providing the necessary personnel at a single site rather than at individual utilities would add a margin of safety, would be more efficient, and would result in substantial cost savings.

Assuming that most plants will operate for the duration of their licenses, relatively few reactors are expected to shut down before the year 2010. However, experience has shown that some reactors, for one reason or another, will shut down before their operating licenses expire. To allow for the contingency of an early shutdown and possible delays in the repository's opening, the Commission believes that a User-Funded Interim Storage facility of limited capacity would be desirable.

Inasmuch as some utilities may wish to ship fuel to a central facility rather than retain it on site, the storage facility would also be available for this purpose.

If repository operation were to be delayed, the longer interim storage at the reactor sites or at the UFIS facility would reduce the heat load placed on the repository, thereby reducing some of the technical uncertainties of geologic disposal. This policy of longer interim storage is being followed in all other countries where nuclear power facilities are operating. (See Appendix D for further discussion of spent fuel storage activities in other countries.)

A Commission contractor estimates that the capital cost of the User-Funded Interim Storage facility would range from about $500 million to $600 million. (See Appendix I, Section One.)

In view of the uncertainties about when the MRS and repository will be in operation, many utilities with newer reactors have already taken steps to provide needed life-of-plant storage, while others have expressed a preference for providing such storage themselves rather than relying on an MRS. For these reasons, the Commission believes that it would be more equitable for the storage facility to be user funded, so that only those utilities that chose to use the facility would pay for it.

User funding of this facility would also be more cost effective in that the cost of the facility could be compared with the cost which individual utilities are paying for on-site storage. Utilities, therefore, would use this facility only if it were more economical than on-site storage or if the additional marginal cost provided benefits otherwise unavailable.

It is not the Commission's role to develop the specific financial basis for determining the fee utilities should pay to use the central facility. However, because of the uncertainty about the number of users and the date a repository may become operational, it is important for utilities to know at an early date the cost of using the central facility. One way to accomplish this purpose would be for DOE to auction the rights to use the facility. If the sum of the bids did not exceed the cost of building and licensing the facility, it would not be built. Subsequent auctions could be held if warranted by delay in the repository or other factors. (For further details about the auction procedure, see Appendix I, Section Three.)

Utilities may find it desirable to pay a reasonable premium to use a central facility instead of at-reactor storage, but the uncertainty of the cost of licensing a contentious facility of this sort may be too great to allow user funding to operate in its purest form. Therefore, the Commission recommends that DOE, in consultation with the NRC, establish an upper limit for licensing cost and exclude costs in excess of that limit from affecting the payment required to use the central facility.

Because present law allows the Nuclear Waste Fund to pay for transportation from the reactor to the repository, the fund should also pay the cost of transporting spent fuel from the reactor to the storage facility.

There is a question whether DOE has a legal obligation under its contract with utilities to take possession of spent fuel by January 31, 1998, with the Nuclear Waste Fund paying the storage cost. Although the Commission believes that Congress should take into account the expectation that DOE would begin to accept fuel by 1998 under the NWPA, the Commission makes no judgment as to whether or not a legal obligation exists.

Questions have already been raised as to the Nuclear Waste Fund's adequacy for financing the repository. The fact that the cost of the UFIS would be paid by the utilities using it rather than from the Nuclear Waste Fund (as would be the case with the MRS) would mitigate, to some degree, increases in the Nuclear Waste Fund that might be needed for constructing the repository.

Because it would defeat the purposes of serving in a timely manner the functions described above, building the 5,000 MTU storage facility should not be linked in time to the repository's construction. However, the limitation on the facility's size would in itself be a "linkage," in that the facility would accommodate only about 6 percent of the fuel to be generated by existing nuclear power plants over their projected lifetime. Thus, the UFIS could not be considered a de facto repository.

As for the facility's size, the Commission believes that 5,000 MTU should be ample for the purposes indicated. The Commission estimates that by 2006 operating and shutdown reactors will require about 9,000 MTU of dry storage. Assuming that utilities desired to store in the central facility as much as half of their spent fuel from operating and shutdown reactors, 5,000 MTU should be sufficient to provide for such requirements at least until 2006.

Recommendation No. 3. Congress should reconsider the subject of interim storage by the year 2000 to:
(a) take into account uncertainties that exist today and that might be resolved or clarified within ten years, (b) consider developments that cannot be anticipated today, and (c) evaluate the experience with the two facilities recommended above.

As has been indicated throughout this report, there are many uncertainties which make it extremely difficult to plan for long-term interim storage of spent fuel. Although the date of opening a permanent repository is the most notable uncertainty, many other questions, such as those noted below, also remain unresolved.

The Commission believes that the actions recommended above should adequately take care of the needs of interim storage at least until 2006. The Commission arrived at this conclusion after considering the schedule of cumulative need for spent fuel storage, the option of at-reactor storage, and the fact that the need for storage will become acute only after a significant number of reactors shut down and if neither an MRS nor a repository is available.

However, by the year 2000, Congress should reconsider the question of interim storage of spent fuel, taking into account, among other things, the following factors:

a. Status of the repository;

b. Status of nuclear power plants, i.e., number that shut down early, license extensions, utilization of extended burnup, etc.;

c. Availability of at-reactor storage;

d. Utilization and adequacy of the 2,000 MTU Federal Emergency Storage facility;

e. Utilization and adequacy of the 5,000 MTU User-Funded Interim Storage facility;

f. Status of rod consolidation, dual-purpose casks, and other technological developments in spent fuel storage;

g. System optimization; and

h. The fee schedule established for the user-funded facility.

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The Monitored Retrievable Storage Review Commission believes that these recommendations, together with analyses contained in other sections of this report, carry out the Commission's mandate from Congress. If implemented, the recommendations would provide safe interim storage of spent nuclear fuel, would be consistent with the goals of the national nuclear waste management system, and would provide for flexibility and unforeseen contingencies.

The Commission urges Congress, whatever its decision, to act as promptly as possible with regard to interim spent fuel storage, so that DOE, utilities, and other affected parties can plan accordingly.

Appendix A
Public Hearings: People Appearing Before the Commission

Washington, D.C.

December 1–2, 1988

Scheduled Witnesses:

1. Mr. William W. Berry, Chairman of the Boards of Dominion Resources and Virginia Power, and Chairman of the American Committee on Radioactive Waste Disposal, Edison Electric Institute, Washington, D.C.; accompanied by Mr. Steven Kraft, Director, Nuclear Waste and Transportation Program, Edison Electric Institute, Washington, D.C.

2. Mr. Paul Childress, Project Manager, Nuclear Power Division, Babcock and Wilcox, Lynchburg, Virginia, and High-Level Radioactive Waste Committee of the American Society of Mechanical Engineers

3. Mr. Anton Fuierer, Director, Special Projects, Rochester Gas and Electric Company, Rochester, New York

4. Mr. William Hamilton, Manager, Nuclear Waste Department, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania

5. Ms. Judith Johnsrud, Ph.D., Director, Environmental Coalition on Nuclear Power, State College, Pennsylvania, and Research Director, Food and Water Inc., Denville, New Jersey

6. Mr. Leon Lowery, Legislative Representative, Environmental Action, Washington, D.C.

7. Mr. Dick Nelson, Chair, Energy and Utilities Committee, House of Representatives, State of Washington, Olympia, Washington

8. Mr. Karl J. Notz, Chairman, MRS Information Group, Oak Ridge, Tennessee

9. Ms. Caroline Petti, Legislative Director, Southwest Research and Information Center, Washington, D.C.

10. Reverend Margaret Schmitz, Pastor, Maybeury, West Virginia

11. Mr. Ben L. Smith, Executive Administrative Assistant III, Tennessee State Planning Office, Nashville, Tennessee

12. Mr. David Snedecker, Consultant, Pullyaup, Washington

13. Mr. Michael McK. Wilson, Commissioner, Florida Public Service Commission, and Chairman, NARUC Subcommittee on Nuclear Waste Disposal, Tallahassee, Florida

Walk-In Testimony:

14. Mr. Raymond E. Hoskins, Spent Nuclear Fuel Management Consultant, Chattanooga, Tennessee

Denver, Colorado

January 5, 1989

Scheduled Witnesses:

15. Mr. Jeff Everitt, Technological Hazards Officer, State Department of Emergency Services, Golden, Colorado

16. Mr. Timothy Holeman, Policy Advisor to Governor Roy Romer of Colorado, on behalf of the Western Interstate Energy Board's High-Level Radioactive Waste Committee, Denver, Colorado

17. Mr. Kirkland Jones, Deputy Director, Environmental Improvement Division, Santa Fe, New Mexico

18. Ms. Melinda Kassen, Senior Attorney, Environmental Defense Fund, Boulder, Colorado

19. Mr. Tony Massaro, Director of Environmental Affairs, City and County of Denver, Colorado

20. Mr. Rex J. Massey, Associate, Intertech Consultants, Inc., Carson City, Nevada, on behalf of Lincoln County and the City of Caliente, Nevada

Walk-in Testimony:

21. Mr. George Durkop, Coordinator, Douglas County Emergency Services, Douglas County, Colorado

22. Mr. Wyatt M. Rogers, Jr., Nuclear Projects Manager, Council of Energy Resource Tribes, Denver, Colorado

San Francisco, California

January 9, 1989

Scheduled Witnesses:

23. Mr. Dennis Bechtel, Coordinator, Clark County Comprehensive Planning Department, on behalf of Clark County, Nevada

24. Mr. Wallace Behnke, Vice Chairman, Commonwealth Edison Company, Chicago, Illinois

25. Mr. Leonard Conly, Secretary, Nuclear-Free Berkeley Committee, Berkeley, California

26. Dr. Richard Ferguson, Regional Vice President for Southern California/Nevada Sierra Club, Creston, California

27. Mr. Steve Frishman, Technical Policy Coordinator, Nevada Agency for Nuclear Projects, Carson City, Nevada

28. Mr. Roger Herried, Staff Person, Abalone Alliance, San Francisco, California

29. Mr. Donald W. Mazur, Managing Director, Washington Public Power System, Richland, Washington

30. Mr. Max S. Power, Program Director, Office of Nuclear and Mixed Waste, Washington Department of Ecology, on behalf of the Washington State Nuclear Waste Board and Nuclear Waste Advisory Council, Olympia, Washington

31. Mr. James D. Shiffer, Vice President of Nuclear Power Generation, Pacific Gas and Electric Company, San Francisco, California

Walk-In Testimony:

32. Mr. Andy Colonna, Private Citizen, Arcata, California

33. Mr. Don Eichelberger, Staff Person, Abalone Alliance, San Francisco, California

34. Mr. Bob Fulkerson, Executive Director, Citizen Alert, Las Vegas, Nevada

35. Ms. Helen Hubbard, President, and Ms. Diane Hughes, Vice President, Citizens for Total Energy, Sunol, California

36. Mr. Richard G. McPherson, Senior Executive Officer, The McPherson Group, Inc., Costa Mesa, California

37. Ms. Wendy Oser, Private Citizen, Berkeley, California

Atlanta, Georgia

January 17–18, 1989

Scheduled Witnesses:

38. Mr. Robert Anderson, Executive Director of Engineering, Chem-Nuclear Systems, Inc., Columbia, South Carolina

39. Mr. John Barber, County Manager, Davie County, Mocksville, North Carolina

40. Mr. Jeffrey J. Broughton, City Manager, on behalf of the Honorable Roy Pruett, Mayor of Oak Ridge, Tennessee; accompanied by Mr. William D. Harris, Fire Chief, Oak Ridge, Tennessee

41. Mr. Tom Clements, Private Citizen, Atlanta, Georgia

42. Dr. David Corcoran, Publisher of the Welch Daily News, and Chair of the MRS Task Force, Welch, West Virginia

43. Mr. W.G. (Bill) Counsil, Vice Chairman, Texas Utilities Electric, Dallas, Texas

44. Mr. Wells Eddleman, Staff Scientist, North Carolina Citizens Research Group, Durham, North Carolina

45. Ms. Louise Gorenflo, Rural Cumberland Resources, Crossville, Tennessee

46. Mr. Dennis Hoffarth, Private Citizen, Atlanta, Georgia

47. Ms. Carol Jackson, MRS Coordinator, West Virginia Citizens for a Clean Environment, Brooks, West Virginia

48. Mr. Tim Johnson, Co-Director, Campaign for a Prosperous Georgia, Atlanta, Georgia

49. Mr. Andrew Maier, President, Save Our Mountains, Hinton, West Virginia

50. Mr. T.C. McMeekin, Vice President, Design Engineering, Duke Power Company, Charlotte, North Carolina; accompanied by Mr. Gregory Snipes, Nuclear Fuel Supervisor, Duke Power Company, Charlotte, North Carolina

51. The Honorable Mike Parker, U.S. House of Representatives, 4th District, State of Mississippi

52. Dr. Lamar Priester, Chairman, South Carolina Nuclear Waste Consultation Committee, and Representative Harriet Keyserling, South Carolina Nuclear Waste Consultation Committee, on behalf of the State of South Carolina

53. Mr. Ben L. Smith, Executive Administrative Assistant III, Tennessee State Planning Office, Nashville, Tennessee

54. Mr. J.D. Stephens, President, Oil, Chemical and Atomic Workers International Union 3–288, Oak Ridge, Tennessee

55. Ms. Carol Thorup, Senior Vice President, Nuclear Assurance Corporation, Norcross, Georgia

56. Mr. Joe Wilder, Board Member, Lower Savannah Council of Governments, Aiken, South Carolina; accompanied by Mr. Wesley Smith, Attorney at Law, Aiken, South Carolina

57. Mr. William Willis, Executive Vice President and Chief Operating Officer, Tennessee Valley Authority, Knoxville, Tennessee; accompanied by Mr. David L. Dunn, Project Manager, Division of Nuclear Services, Tennessee Valley Authority, Chattanooga, Tennessee

Walk-In Testimony:

58. Dr. John Croom, on behalf of Frances Close Hart, Chairwoman, Energy Research Foundation, Columbia, South Carolina

59. Ms. Glenn Carroll, Private Citizen, Decatur, Georgia

60. Dr. Geoffrey G. Eichholz, Regents Professor, Nuclear Engineering and Health Physics Program, Georgia Institute of Technology, Atlanta, Georgia

61. Ms. Carol Ford, Member, Save Our Cumberland Mountains, Jacksboro, Tennessee

62. Mr. Michael F. Lowe, Private Citizen, Columbia, South Carolina

63. Mr. Leon Lowery, Legislative Representative, Environmental Action, Washington, D.C.

64. Dr. Edward Passerini, Associate Professor, New College, University of Alabama, Tuscaloosa, Alabama

65. The Honorable Doug Teper, State Representative, 46th District, Atlanta, Georgia

Atlanta, Georgia

February 16–17, 1989

Scheduled Witnesses:

66. Mr. Ralph Beedle, Vice President, Nuclear Support Systems, New York Power Authority, White Plains, New York

67. Mr. John Blackburn, Legislative Assistant, on behalf of the Honorable Terry Sanford, U.S. Senate, State of North Carolina

68. Mr. John T. Brock, Davie County Attorney, Mocksville, North Carolina

69. Dr. E. William Coglazier, Jr., Director, Energy, Environment and Resources Center, University of Tennessee, Knoxville, Tennessee

70. Ms. Claudine Cremer, District Assistant, on behalf of the Honorable James McClure Clarke, U.S. House of Representatives, 11th District, State of North Carolina

71. Mr. Donald A. Downs, President, Davie Opposes Nuclear Trash, Advance, North Carolina

72. Ms. Martha Drake, Board Member, Conservation Council of North Carolina, Chapel Hill, North Carolina

73. Ms. Laura Drey, News Editor, Coalition for Alternatives to Shearon Harris, Durham, North Carolina

74. Mr. Raymond E. Hoskins, Spent Nuclear Fuel Management Consultant, Chattanooga, Tennessee

75. Ms. Janet Hoyle, President, Blue Ridge Environmental Defense League, Glendale Springs, North Carolina

76. Mr. J. Michael Martinez, Assistant Director, Policy Analysis, Southern States Energy Board, Norcross, Georgia

77. Mr. Bill McEwen, Administrative Assistant, on behalf of the Honorable W.G. (Bill) Hefner, U.S. House of Representatives, 8th District, State of North Carolina

78. Ms. Elizabeth Peelle, Consultant, Socio Economic Study Group, MRS Task Force, Oak Ridge, Tennessee

79. Mr. Jesse L. Riley, Chairman of the Nuclear Subcommittee, Sierra Club National Energy Committee, Charlotte, North Carolina

80. Ms. Jane Sharp, Board Member, Conservation Council of North Carolina, Chapel Hill, North Carolina

81. Mr. Harrison M. Wadsworth, III, Staff Member, on behalf of the Honorable Bart Gordon, U.S. House of Representatives, 6th District, State of Tennessee

82. Mr. Louis Zeller, Secretary, Elk River Coalition, Marshall, North Carolina

Walk-in Testimony:

83. Mr. Robert Morgan, Private Citizen, Aiken, South Carolina

84. Dr. Edward Passerini, Associate Professor, New College, University of Alabama, Tuscaloosa, Alabama

Appendix B

Statements Submitted For the Record

The following people have submitted written statements for the record in lieu of appearing during a hearing before the Commission. The names appear in alphabetical order.

James Adams, Redwood Alliance, Arcata, California

Debby Beaver, Concerned Citizen, Red Boiling Springs, Tennessee

Patricia Birnie, Co-Director, Maryland Safe Energy Coalition, Columbia, Maryland

David A. Boggs, General Manager, Sacramento Municipal Utility District, Sacramento, California

J. M. Buchheit, Senior Nuclear Fuels Engineer, Yankee Atomic Electric Company, Boston, Massachusetts

Emily B. Calhoun, Concerned Citizen, Atlanta, Georgia

Gaston Caperton, Governor, State of West Virginia, Charleston, West Virginia

William W. Cobey, Jr., Secretary, North Carolina Department of Natural Resources and Community Development, Raleigh, North Carolina

Michael Cohen, Concerned Citizen, Gaithersburg, Maryland

Mary Lula Cook, Concerned Citizen, Advance, North Carolina

Dorothy Cope, Concerned Citizen, Spencer, Tennessee

Diane D'Arrigo, Nuclear Information and Resource Service, Washington, D.C.

Joan Edwards, Energy Chair, Sierra Club Cascade Chapter, Bellevue, Washington

Helen Everett, Concerned Citizen, Hinton, West Virginia

Jean Ewing, Peach Bottom Alliance, Darlington, Maryland

The Honorable Albert Gore, Jr., U.S. Senate, State of Tennessee

William J. Hafner, Concerned Citizen, Mastic, New York

Judge Peter W. Hairston and Lucy D. Hairston, Concerned Citizens, The Cooleemee Plantation, Advance, North Carolina

Shirley P. Hendrix, Chairman, Transportation Study Group, MRS Clinch River Task Force, Oak Ridge, Tennessee

Victor H. Hoffman, High Rock Lake Association, Southmont, North Carolina

Jacqueline D. Hubbs, Concerned Citizen, Cookeville, Tennessee

William G. Jasen, Concerned Citizen, West Richland, Washington

Susan Jata, Concerned Citizen, Nashville, Tennessee

Cheryl D. Jay, Concerned Citizen, Savannah, Georgia

Andrew Jenkins, Department of Energy & Transportation, Jackson, Mississippi

Judith H. Johnsrud, Ph.D., Environmental Coalition on Nuclear Power, State College, Pennsylvania

Eva R. Jurgensen, Concerned Citizen, Advance, North Carolina

Donald B. Karner, Executive Vice President, Arizona Nuclear Power Project, Phoenix, Arizona

Leah R. Karpen, Concerned Citizen, Weaverville, North Carolina

Joan O. King, Concerned Citizen, Sautee, Georgia (Ms. King submitted two statements for the record.)

Susan Lange, Concerned Citizen, Rock Cave, West Virginia

Drew Langsner, Concerned Citizen, Marshall, North Carolina

Marvin I. Lewis, Concerned Citizen, Philadelphia, Pennsylvania

William S. Lewis, Attorney at Law, Savannah, Georgia

Patricia Link, Co-Chairperson, Rowan Environmental Action Partners, Salisbury, North Carolina

Noel P. McJunkin, Concerned Citizen, Tellico Plains, Tennessee

Douglas Moore, Concerned Citizen, Cookeville, Tennessee

Carl Mortenson, Concerned Farmer, Natty Locks Farm, Moyers, West Virginia

The Honorable Stephen L. Neal, U.S. House of Representatives, 5th District, State of North Carolina

Robert Jack Neff, Chairman, MRS Study Committee of the Tennessee Chapter of the Sierra Club, Nashville, Tennessee

L.T. Papay, Senior Vice President, Southern California Edison Company, Rosemead, California

Robert Peelle, Commissioner, 4th District, Roane County, Oak Ridge, Tennessee

Jeff Poppen, Concerned Farmer, Long Hungry Creek Nursery, Red Boiling Springs, Tennessee

The Honorable John D. Rockefeller, U.S. Senate, State of West Virginia

William Alan Ross, Concerned Songwriter, Nashville, Tennessee

The Honorable Jim Sasser, U.S. Senate, State of Tennessee

The Honorable Jim Sasser and The Honorable Albert Gore, Jr., U.S. Senate, State of Tennessee

Betty Schroeder, GE Stockholders' Alliance, Columbia, Maryland

James M. Sconyers, Concerned Citizen, Terra Alta, West Virginia

Steven Gerry Scudder, Concerned Citizen, Murfreesboro, Tennessee

Sierra Club, West Virginia Chapter, Morgantown, West Virginia

Valerie Slogick, Teacher, and students in her 6th grade class, William R. Davie Elementary School, Mocksville, North Carolina

Nan Smyth, President, League of Women Voters of South Carolina, Columbia, South Carolina

Rick Spry, Concerned Citizen, Mocksville, North Carolina

J. Thomas Tidd, Vice President and General Counsel, Association of American Railroads, Washington, D.C.

Marshall E. Tyler, Concerned Citizen, Mocksville, North Carolina

Susan M. White, Concerned Citizen, Whitleyville, Tennessee

Ken Yager, County Executive, Office of the County Executive, Roane County Courthouse, Kingston, Tennessee

Sally Yancey, Concerned Citizen, Pleasant Shade, Tennessee

Steven Yancey, Concerned Citizen, Pleasant Shade, Tennessee

Appendix C

Public Briefings: People Appearing Before the Commission

Briefing on History and Background of MRS Program

July 25, 1988:

In Order of Appearance:

1. Mr. Thomas H. Isaacs, Acting Associate Director, Office of External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.
2. Mr. James Carlson, Chief, Program Relations Branch, Office of External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.
3. Mr. Keith A. Klein, Deputy Associate Director for Systems Integration and Regulation, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.
4. Mr. Robert Bernero, Director, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.
5. Mr. Leland C. Rouse, Chief, Fuel Cycle Safety Branch, Division of Industrial and Medical Safety, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.
6. Mr. A. Thomas Clark, Senior Chemical Engineer, Fuel Cycle Safety Branch, Division of Industrial and Medical Safety, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.
7. Mr. Benjamin Cooper, Professional Staff Member, Committee on Energy and Natural Resources, U.S. Senate, Washington, D.C.
8. Mr. Dan M. Berkovitz, Counsel, Committee on Environment and Public Works, U.S. Senate, Washington, D.C.
9. Mr. Sam E. Fowler, Counsel, Subcommittee on Energy and the Environment, Committee on Interior and Insular Affairs, U.S. House of Representatives, Washington, D.C.
10. Mr. David Schooler, Professional Staff Member, Subcommittee on Energy and Power, Committee on Energy and Commerce, U.S. House of Representatives, Washington, D.C.
11. Mr. Louis Ventre, Counsel, Subcommittee on Energy Research and Development, Committee on Science, Space, and Technology, U.S. House of Representatives, Washington, D.C.

July 26, 1988:

In Order of Appearance:

1. Mr. Ben L. Smith, Executive Administrative Assistant III, Tennessee State Planning Office, Nashville, Tennessee
2. Dr. E. William Coglazier, Jr., Director, Energy, Environment and Resources Center, University of Tennessee, Knoxville, Tennessee
3. Mr. Raymond E. Hoskins, Spent Nuclear Fuel Management Consultant, Chattanooga, Tennessee
4. Dr. Ruth Neff, Tennessee State Planning Office, Tennessee Department of Health and Environment, Nashville, Tennessee
5. The Honorable Bart Gordon, U.S. House of Representatives, 6th District, State of Tennessee
6. Mr. Keith Fultz, Senior Associate Director, Resources, Community and Economic Development Division, General Accounting Office, Washington, D.C.
7. Mr. Dwayne Weigel, Group Director, Resources, Community and Economic Development Division, General Accounting Office, Washington, D.C.
8. Mr. Vincent Price, Evaluator, Resources, Community and Economic Development Division, General Accounting Office, Washington, D.C.

July 27, 1988:

In Order of Appearance:

1. Mr. Richard C. Hannon, Chief, Policy Development and Information Systems Division, Research and Special Programs Administration, Department of Transportation, Washington, D.C.
2. Mr. Michael E. Wangler, Chief, Radioactive Materials Branch, Technical Division, Research and Special Programs Administration, Department of Transportation, Washington, D.C.

3. Mr. Larry Bruno, Senior Policy Analyst, Policy Development and Information Systems Division, Research and Special Programs Administration, Department of Transportation, Washington, D.C.

4. Dr. Richard W. Lynch, Director of Nuclear Waste Management and Transportation, Sandia Laboratories, Albuquerque, New Mexico

5. Mr. Joseph E. Stiegler, Manager, Transportation System Development Department, Sandia Laboratories, Albuquerque, New Mexico

6. Dr. George C. Allen, Jr., Supervisor, Transportation Systems Technology Division, Sandia Laboratories, Albuquerque, New Mexico

7. Dr. Robert E. Luna, Supervisor, Risk Assessment and Transportation System Analysis Division, Sandia Laboratories, Albuquerque, New Mexico

8. Mr. Loring Mills, Vice President, Nuclear Activities, Edison Electric Institute, Washington, D.C.

9. Mr. John Kaufmann, Executive Vice President, Pennsylvania Power & Light Company, Allentown, Pennsylvania

10. Mr. D.A. Brodnick, Senior Licensing Specialist, Florida Power and Light Company, Miami, Florida

11. Mr. Steven Kraft, Director, Nuclear Waste and Transportation Group, Edison Electric Institute, Washington, D.C.

12. Mr. Daniel Reicher, Senior Project Attorney, Natural Resources Defense Council, Washington, D.C.

13. Ms. Caroline Petti, Legislative Director, Southwest Research and Information Center, Washington, D.C.

Briefing by the Nuclear Regulatory Commission Staff

Cask Certification and NRC Licensing of ISFSI

September 22, 1988:

1. Mr. Charles E. McDonald, Chief, Transportation Branch, Division of Safeguards and Transportation, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.

2. Mr. Leland C. Rouse, Chief, Fuel Cycle Safety Branch, Division of Industrial and Medical Nuclear Safety, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.

3. Mr. John Roberts, Section Leader, Irradiated Fuel Section, Division of Industrial and Medical Nuclear Safety, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.

4. Mr. John W. Craig, Chief, Plant Systems Branch, Division of Engineering and Technology, Office of Nuclear Reactor Regulation, Nuclear Regulatory Commission, Washington, D.C.

Briefing by the Department of Energy

Engineering Studies, Rod Consolidation, Cask Development

September 23, 1988:

1. Mr. Thomas H. Isaacs, Acting Associate Director, Office of External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

2. Mr. Ralph Stein, Acting Associate Director, Office of Systems Integration and Regulations, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

Briefing by the Department of Energy

Permanent Repository Program

December 15, 1988:

1. Mr. Sam Rousso, Acting Director, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

2. Mr. Thomas H. Isaacs, Associate Director, Office of External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

3. Mr. Carl Gertz, Project Manager, Yucca Mountain Project Office, Department of Energy Nevada Operations Office, Las Vegas, Nevada

4. Mr. Jerome D. Saltzman, Acting Deputy Associate Director, Office of Facilities, Siting and Development, Department of Energy, Washington, D.C.

Briefing by the Department of Energy

Preliminary Results of Systems Studies

March 16, 1989:

1. Mr. Thomas H. Isaacs, Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

2. Mr. Ralph Stein, Associate Director, Office of Systems Integration and Regulations, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

Briefing by the Department of Energy

Position on Need for an MRS Facility

May 25, 1989:

1. Mr. Thomas H. Isaacs, Associate Director, External Relations and Policy, Office of Civilian Radioactive Waste Management, Department of Energy, Washington, D.C.

Briefing by the Nuclear Regulatory Commission

Safety and Safeguards Issues

May 25, 1989:

1. Mr. George McCorkle, Deputy Director, Division of Safeguards and Transportation, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.

2. Mr. Leland Rouse, Chief, Fuel Cycle Safety Branch, Division of Industrial and Medical Nuclear Safety, Office of Nuclear Material Safety and Safeguards, Nuclear Regulatory Commission, Washington, D.C.

Appendix D

Spent Fuel Management Policies in Eight Countries

Prepared for
The Monitored Retrievable Storage Review Commission

By

JK Research Associates, Inc.
3408 Bonnie Road
Austin, TX 78703

October 10, 1989

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TABLE OF CONTENTS

1.0 CANADA

1.1 Status of Nuclear Power and Waste Management

Canada has 18 operating reactors (just over 11 GWe) that supply about 13 percent of the country's electricity.[1] An additional four reactors are being commissioned or are under construction. These reactors are all of the natural-uranium CANDU design developed by Atomic Energy of Canada Ltd. (AECL). Existing and projected Canadian reactors are expected to discharge about 34,000 MTU of spent fuel through the end of this century, and a total of about 100,000 MTU by 2050 (if there is no reprocessing.) Reprocessing is not now planned, although no final decision has been made about the ultimate disposition of spent fuel.

1.2 Institutional Structure of Reactor Operation and Waste Management

Sixteen of the 18 Canadian reactors are owned by a single utility, Ontario Hydro. The other two are owned by Quebec Hydro and the New Brunswick Electric Power Commission. Each utility is responsible for the interim management of its own spent fuel. In addition, Ontario Hydro is responsible for development of technology for interim storage and transportation of spent fuel. The Whiteshell Nuclear Research Establishment (WNRE) directs and coordinates an R&D program on immobilization and disposal of nuclear fuel waste. Whiteshell is part of AECL, which reports to the Federal Department of Energy, Mines and Resources. The disposal R&D program is funded jointly by the Federal government and Ontario Hydro. Institutional responsibility for implementation of waste disposal has not been decided, nor has the precise funding mechanism. At present the utilities collect and accrue funds (via electric rates) to cover the estimated costs of spent fuel and waste management, and decommissioning.

Nuclear activities are regulated by the Atomic Energy Control Board (AECB), which reports to the Department of Energy, Mines and Resources along with AECL. In general, the national government has responsibility for all nuclear affairs, with preemptive rights.

1.3 Waste Management Strategy

As noted above, no decision has been made about spent fuel disposal or reprocessing, and current policy is to keep spent fuel in retrievable storage (discussed below) until such a decision is made. The capability to dispose of spent fuel is being developed. There is no legal linkage between reactor operation and availability of a waste repository, and there is no sense of urgency about final disposal. The current plan is for WNRE to issue a concept assessment report evaluating a proposed approach for disposal of spent fuel and high-level waste (HLW). The report will include results of tests at the Underground Research Laboratory (URL) located near the Whiteshell center, although this laboratory is not intended to be the ultimate site of the repository. Review of the report, in the early 1990s, will be coordinated by the Federal Environmental Assessment Review Office, which will bring in various Federal and Ontario governmental agencies and other organizations and organize public hearings. If approval is given after the review process, development of disposal technology will continue, probably with the concurrent evaluation of disposal sites.

1.4 Interim Storage Policy in Detail

1.4.1 Interim storage: facilities and technologies

At present, almost all spent fuel is stored in pools at the reactor sites. There are only six such sites for Canada's reactors. Ontario Hydro has three nuclear centers. The Bruce center is divided into two separate sites with four reactors each; the Pickering center has eight reactors on a single site; and the Darlington center has four reactors either being commissioned or under construction. The other two sites have one reactor apiece. All of the sites were designed with large pool storage capacity; the pools at Bruce and Pickering should be adequate until the mid-1990s, while those at Darlington will be sufficient into the next century. The Ontario Hydro sites have central storage basins connected to groups of four reactors.

A wide range of options for additional spent fuel storage capacity is under consideration, including both wet and dry storage, and off-site as well as on-site storage.[2] Economic studies by Ontario Hydro have shown that adding pool storage may be the most cost-effective option for a large capacity facility. This is the likely option for providing additional storage at the two Bruce sites, since there is adequate room on the sites and the existing pools are designed to facilitate such expansion. The Pickering site is cramped, however, and dry storage, most likely on-site, may be necessary. Ontario Hydro has evaluated four dry storage options: convection-cooled vaults, concrete storage casks, concrete integrated containers (for storage, transportation, and disposal), and metal casks. Ontario Hydro is continuing development of the concrete integrated container, and this is the option that would be used at the Pickering site if dry storage is selected. Canada has extensive experience with storage in concrete casks.[3]

1.4.2 Basis for at-reactor/centralized storage decision

No utility has decided to move off-site for additional storage, and it is possible that any such decision would await satisfactory demonstration of a concept for disposal. Off-site storage may have to be considered eventually for the Pickering reactors because of space limitations on-site.

1.4.3 Financial arrangements for storage

At-reactor storage is paid for directly by the utilities.

1.4.4 Other roles for storage site.

A possible site for offsite storage for Ontario Hydro is the Bruce Nuclear Power Development (BNPD) site. This site is currently used for low- and intermediate-level waste storage and treatment, and is the location of an incinerator.

2.0 FRANCE

2.1 Status of Nuclear Power and Waste Management

France has 51 operating nuclear plants (about 53 GWe capacity, mostly PWRs) that generate more than 70 percent of the electricity produced in that country. France's nuclear power strategy is to maintain a full domestic fuel cycle capability, including reprocessing for domestic and foreign customers and plutonium recycle in light-water and breeder reactors. Spent fuel is stored at reactor sites for only a few years before being shipped to a reprocessing plant. The HLW from reprocessing is vitrified and will be stored for 20 years or longer for cooling before geologic disposal in a repository.

2.2 Institutional Structure of Reactor Operation and Waste Management

French reactors are owned and operated by Electricite de France (EDF) which is 100 percent government-owned. The Commissariat a l'Energie Atomique (CEA) controls nuclear research and development efforts and provides technical support to other companies in their licensing activities. The Compagnie Generale des Matieres Nucleaires (COGEMA) is responsible for fuels production and reprocessing activities. It is a wholly-owned subsidiary of the CEA and owns all of the fuel cycle facilities in France. Although COGEMA is government-owned, it is a commercial venture whose business activities are financed through its investments and paid for by its fuel cycle clients.
EDF is a major client, although it is not required to use COGEMA's reprocessing services. Other clients include utilities in Japan, Germany, and Switzerland.

Long-term waste management activities are controlled by the Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA), an organization within the CEA. The Chairman of the ANDRA Steering Committee is the Administrator of CEA. Other waste producers are members of the Steering Committee including EDF, COGEMA, and hospitals. EDF pays 80 percent of the cost of waste activities; COGEMA pays 10 percent; and CEA pays 10 percent. Research and development is funded by CEA, ANDRA, and DED, the Delegue pour les Effluents et Dechets Radioactifs (part of CEA).

Local communities near nuclear facilities are involved in siting questions through a formal public inquiry process, but do not have a legal veto. However, if there is sufficient local opposition, the siting of the facility in the area will be abandoned.

2.3 Waste Management Strategy

All LWR spent fuel in France is to be reprocessed. Plutonium and uranium are both recycled after reprocessing. The costs of reprocessing are now about equal to the no-reprocessing option but reprocessing reduces the HLW stream and allows the recovery of plutonium.

France first began reprocessing fuel from its defense reactors at Marcoule in a facility called UP1. Additional reprocessing facilities were built at La Hague. The La Hague reprocessing plants are being built in two parts. The first part, UP2, reprocesses French fuel. It first became operational in 1966 when it was used to reprocess gas-cooled reactor (GCR) fuel. It was modified in 1976 to reprocess light water reactor (LWR) fuel and has been used only for LWR fuel since 1985. The second part, UP3, is under construction and will handle foreign fuel until France needs the capacity for its own fuel. Because the French nuclear program has not grown at the predicted rate, France expects to have excess capacity at UP3 for some time. COGEMA and a German energy company, VEBA, have recently announced an agreement in principle for VEBA to acquire 49 percent ownership of UP3, and negotiations are currently in progress.

Spent fuel from LWRs is taken to La Hague to be reprocessed. Fuel from GCRs is reprocessed at the Marcoule facility. Liquid wastes are stored in tanks temporarily before vitrification. All of the wastes from reprocessing of foreign fuels will be stored for 5 years and then shipped back to the country of origin. The vitrified waste from French reactor fuel will be stored for a minimum of 20 years, perhaps substantially longer, before permanent disposal because a repository will not be available before 2010. This gives the opportunity to cool the waste so that the thermal impact on the repository host rock will be reduced.

The French reactors will produce a lifetime total of about 12,000 cubic meters of vitrified HLW, to be disposed of in two or three underground sites. The French are now doing deep drilling to explore four sites in different geologic media: clay, salt, schist, and granite. The schedule calls for the commencement of final placement of the HLW in a repository by the year 2010.

2.4 Interim Storage Policy in Detail

2.4.1 Interim storage: facilities and technologies

Spent fuel from LWRs is stored in spent fuel pools at the reactors for about 1 year before it is taken to La Hague to be reprocessed. Reracking of reactor pools and dry storage at reactor sites are not foreseen for LWR fuel. La Hague has four storage pools with over 11,000 MTU capacity, and LWR fuel is stored there for 2 years until it is reprocessed. Wet pool storage was selected for this stage in the process because it was cheaper than other available storage methods (including dry vault storage) for the known, large lag storage requirements, and the technology has been proven. It also facilitates selection of individual fuel assemblies for reprocessing.

After reprocessing, the liquid HLW is stored on-site at the reprocessing facility in tanks until it can be vitrified. After vitrification, it will be stored in dry storage vaults on site as long as necessary. In the case of UP3, which handles only foreign fuel, this period is only 5 years, after which time the HLW will be returned to the country of origin. For UP2, the storage period will be until a geologic repository is available. The facility was designed with a period of at least 50 years in mind, and the French believe that the period could be extended as long as needed because of the safety of monitored storage. The same is true of the facility at Marcoule. The existing dry storage facility at UP2 has the capacity to store 5 years of production from the vitrification plant. Capacity will be added in 5-year modules as needed.

The CEA is constructing a dry vault storage facility (Cascade) at Cadarache, a CEA-managed nuclear facility, for non-commercial fuel owned by CEA. The impetus for the project was the need to find storage for the fuel from CEA's EL4 heavy water gas-cooled nuclear reactor, which closed in 1986. Intermediate storage for less than 50 years was planned. Casks, pools, vaults, and concrete canisters were considered as alternative storage methods. The advantage of modularity associated with the casks was not important because the quantity of waste was known. Vault storage in stainless steel canisters was selected. The initial planned capacity of the facility is 180 MTU. The capacity of the facility could be increased to 300 metric tons. The CEA currently plans to store submarine spent fuel and experimental fuels at Cascade in addition to EL4 fuel. Cascade is scheduled to become operational in 1989.

2.4.2 Basis for at-reactor/centralized storage decision

There has been no formal consideration of whether to store spent fuel at reactors or elsewhere. French policy to reprocess all fuel fairly promptly has obviated the need for such a decision. The reprocessing facilities have been built with sufficient front-end buffer capacity to handle contingencies. They were also designed to store all vitrified waste on site as long as necessary.

2.4.3 Financial arrangements for storage

Front-end storage at reprocessing plants is included in the reprocessing charge.

2.4.4 Other roles for storage site

As noted, the spent fuel and HLW storage facilities are ancillary to the primary activity at Marcoule and La Hague, reprocessing.

2.4.5 Technical experience

Perhaps the most relevant experience for the U.S. is the experience with the spent fuel receiving and handling facilities at La Hague. There are two unloading facilities, NPH (wet) and T zero (dry) that receive spent fuel in transportation casks, remove the fuel, prepare it for storage, and transfer it to one of the four storage pools at the site. NPH has two unloading lines with a combined capacity of 800 metric tons per year, while T zero has a single line with the same total capacity as the two wet lines. The throughput capacity of T zero is comparable to that planned for individual lines at DOE's proposed MRS facility.

All activities in the dry unloading facility are automated and done remotely. More than 200 casks have been unloaded since the opening of the dry cell in 1986. The dry cell will only handle standardized casks (four types), while NPH can handle any kind of cask. Dry handling is preferred because wet storage generates more waste, especially contaminated water.

Because of remote handling and automation (which reduces the number of workers needed), the dry facility has achieved individual worker doses that are far below those at the wet facility, and only one percent of the regulatory limit. Specifically, in 1987 the average dose per worker per year at T zero was only 50 millirem for an annual receipt rate of 800 MTU, compared to 320 millirem at NPH and a regulatory limit of 5 rem.[4]

3.0 FEDERAL REPUBLIC OF GERMANY

3.1 Status of Nuclear Power and Waste Management

The Federal Republic of Germany (FRG) has 21 operating nuclear power plants (about 23 GWe) which provide about 40 percent of the electric power produced in the FRG.[5] No further construction of nuclear power plants is anticipated in the foreseeable future, in part because of negative public attitudes towards nuclear activities following the Chernobyl accident.[6]

German reactors have been projected to discharge about 9,000 MTU of spent fuel through the end of this century.[7] Light-water reactor (LWR) fuel is normally transferred to reprocessing facilities (primarily in France and the UK) within 7–10 years after discharge. It is expected that return shipments of vitrified HLW from that reprocessing will begin in 1992.

3.2 Institutional Structure of Reactor Operation and Waste Management

The FRG's nuclear plants are owned by 11 different utilities. The utilities are responsible for management of spent fuel and use the services of their jointly-funded company DWK (the German Company for Reprocessing of Spent Nuclear Fuel). Individual utilities are responsible for at-reactor storage, while a subsidiary of DWK, the Fuel Element Storage Company Gorleben Ltd. (BLG), operates the interim storage facility for spent fuel elements and radioactive waste materials at Gorleben on behalf of the utilities. (Other storage facilities that are under development are discussed below.)

The Federal government in the FRG is responsible for the establishment of repositories for the final disposal of HLW and spent fuel (if any is disposed of directly without reprocessing). The Federal Science and Engineering Agency, PTB, is the organization directly responsible for collection, storage and final disposal of radioactive waste. The PTB has contracted with the German Company for the Construction and Operation of Repositories for Waste (DBE) for designing, constructing, and operating a repository for the permanent disposal of waste. DWK is one of four parent companies of DBE. Nuclear power producers pay current waste management costs and accumulate reserves for future decommissioning of nuclear facilities and waste management.

Waste management activities are federally licensed, but the State governments actually issue the licenses, acting in the name of the Federal government. A formal public hearing is required and is organized by the State licensing authority. Public intervention is allowed in licensing proceedings. In principle, local governments do not have a legal veto, although in practice it could be difficult to force them to accept a waste facility against their will.

3.3 Waste Management Strategy

Federal law requires the recycling of spent fuel if economically and technically feasible. The FRG currently sends its spent fuel to France, the U.K., and the WAK pilot plant in the FRG for reprocessing. Until very recently there were plans for construction and operation of a domestic reprocessing plant at Wackersdorf, but those plans were halted when a German energy company, VEBA, announced the intention to acquire 49 percent ownership of the UP3 reprocessing facility at La Hague, France. This will provide reprocessing capacity of about 400 MTU per year by the end of the century.[8]

While recycling is currently required by law, the FRG is also developing the capability for direct disposal of spent fuel. This is consistent with the recommendations of a study comparing reprocessing and once-through fuel cycles performed for the Federal Ministry of Research and Technology. This study concluded in 1985 that direct disposal of spent fuel would be less expensive than reprocessing and thermal recycle in the foreseeable future, but recommended construction of a reprocessing plant because reprocessing appeared to be "indispensable on the grounds of energy policy."[9] At the same time, it recommended development of the capability for direct disposal of spent fuel.[10]

Currently, spent fuel is stored in spent fuel pools at reactor sites until it is shipped away for reprocessing. Most reactors have 3–10 year pool storage capacity, using compact racks. As discussed below, facilities for dry cask storage of spent fuel and/or returned HLW have been built at three sites, although it is uncertain how many of them will actually operate.

Solidified HLW is destined for deep geologic disposal. The Gorleben salt dome is under investigation as a candidate site for a permanent repository. Exploratory drilling has been conducted at Gorleben and exploratory shafts are being sunk. Two disposal concepts are being pursued: emplacement of self-shielded casks in tunnels, and emplacement of canisters of waste into boreholes about 300 meters deep. The currently-expected date for operation of the repository is the year 2008.

DWK is developing a triple-purpose cask, the Pollux system, which would be used for transportation, storage, and disposal of consolidated spent fuel. The weight limit on these casks is 65 metric tons because of the limits in cask handling capability of the equipment to be used to lower the casks down the repository shafts. Dry rod consolidation is being investigated, and a pilot facility that will test "conditioning" (disassembly and consolidation) of spent fuel in casks and canisters at a small scale is in the licensing stage. Consolidation would double the capacity of each cask (to a total of eight PWR fuel assemblies plus the associated skeletons) at a cost expected to be small compared to the savings resulting from use of fewer universal casks. The fuel would be stored for decades before disposal to allow the thermal output to decrease.

3.4 Interim Storage Policy in Detail

3.4.1 Interim storage: facilities and technologies

DWK planned three 1,500 MTU supplemental spent fuel storage facilities: one, at the site of the planned reprocessing facility at Wackersdorf, was intended for receipt and storage of spent fuel at the front end of the reprocessing plant; the other two, at Ahaus and Gorleben, were to be independent interim storage facilities.[11] (Gorleben was initially intended to be the site of an integrated fuel cycle complex including a reprocessing plant as well as a final repository. The storage facility would have served as storage for fuel prior to reprocessing. However, the reprocessing plant did not materialize, and the storage facility, originally licensed for storage of spent fuel, is now, in addition, being licensed for storage of HLW to be returned from France.)

The Gorleben facility has been completed, and the Ahaus facility should be completed this summer. However, the date for actual receipt of radioactive material at any of the facilities is uncertain. Gorleben received an operating permit for storage of spent fuel in 1983, but the permit is under litigation; only low-level waste (LLW) is now being stored there. While a storage license has been granted for Ahaus, legal interventions are still possible, and the anticipated initial receipt of spent fuel from the high-temperature gas cooled reactor next year is not certain. The storage facility at Wackersdorf has been almost completed. However, the political leaders in the state say that there will be no nuclear facilities at the site, so the site is being converted to other uses.

Gorleben has the capacity to store 1,500 metric tons of spent fuel or HLW in dry storage for up to 40 years. The spent fuel or HLW will be stored in nodular cast iron casks similar to those used at the Virgina Electric Power Company's Surry reactor. These casks have been licensed for transportation as well as storage in the FRG (the U.S. Nuclear Regulatory Commission [NRC] objects to the use of cast iron in transportation casks in the U.S). Up to 420 casks will be stored in a large building designed for weather protection and shielding.

DWK officials have indicated that dry cask technology was selected instead of wet storage for several reasons: 1) it is cheaper than wet storage; 2) it is passive; 3) it can be designed for no releases; 4) there is no technical limit on its lifetime; 5) it is easy to decommission; 6) it is more politically acceptable because it appears less permanent; 7) there are advantages to using the casks for both transportation and storage; and 8) it is flexible in that additional storage capacity can be added easily.

3.4.2 Basis for at-reactor/centralized storage decision

At-reactor storage of either HLW or spent fuel outside of the reactor pools would have required a change to the licenses which could have resulted in hearings and the possible loss of the operating licenses.

Another factor was the legal requirement that reactor operators specify how spent fuel will be managed 6 years in advance. This requirement could be met by reprocessing contracts covering the fuel, or by availability of an interim storage facility for fuel not yet subject to such contracts.[12]

Local concerns about the duration of storage at the interim facilities did arise, and the state government asked that a license for Ahaus not be granted until the suitability of a final disposal site had been demonstrated.[13] While this stipulation was not adopted, the concern was addressed by assurances that the casks were transport casks that could be moved at any time.

3.4.3 Financial arrangements for storage.

The storage capacity at the Gorleben facility is divided among the DWK shareholder utilities according to their shares. They share operating costs, including depreciation of the investment, whether or not they use the facility. They will pay the additional cost of the dry storage containers required for any fuel they do ship to the facility, giving some economic incentive to maximize pool storage first. (There is no such incentive in the case of fuel covered by reprocessing contracts with COGEMA, since the reprocessing fee covers the cost of any interim storage of spent fuel required at the reprocessing plant.)

3.4.4 Other roles for storage site

The Gorleben facility is currently used to store low-level wastes. In addition, DWK plans to construct a pilot plant for spent fuel conditioning adjacent to the interim storage facility. The throughput of the plant will be limited to 35 metric tons of uranium per year. The facility will demonstrate the techniques of conditioning and encapsulation of radioactive wastes for final disposal in casks; encapsulating wastes in a form suitable for final storage; unloading vitrified HLW from transport casks into storage casks for interim or final storage; and maintaining transport and storage casks. DWK submitted a license application for the facility in May, 1986 and hopes to begin operations by 1994.

4.0 JAPAN

4.1 Nuclear Power

Japan has 36 nuclear reactors (about 28 GWe capacity) that generate approximately 32 percent of the nation's electricity. An additional 15 reactors (with about 15 GWe capacity) are under construction.[14] The plants are located at 15 different coastal sites.[15] Japan plans a complete nuclear fuel cycle including recycling of plutonium to breeder reactors beginning about 2020, and to advanced thermal and light water reactors. Current law requires that reactor owners must identify a means of reprocessing spent fuel in Japan or abroad. Reprocessing is currently being carried out in France and the U.K. and to a small extent at the Tokai Mura facility in Japan. A large new reprocessing plant is planned to begin operation at Rokkashomura in 1998; the license application for this facility was submitted in March 1989 and receipt of spent fuel at the facility's storage pool is expected to begin in 1994.

4.2 Institutional Structure for Reactor Operation and Waste Management

Japan's nuclear reactors are owned by nine major utility companies. Japan Nuclear Fuel Service Company (JNFS), established by those companies, is responsible for commercial reprocessing, including solidification and interim storage of reprocessing wastes, and for construction and operation of storage facilities for wastes returned from foreign reprocessors of Japanese fuel. The Power Reactor and Nuclear Fuel Development Co. (PNC), which reports to the national Atomic Energy Bureau, is the main governmental organization responsible for research and development on technology for HLW management and for surveying for possible repository sites. The Federal government is ultimately responsible for implementing HLW disposal, but no particular organization has been identified for carrying out that responsibility. The waste generators would pay for disposal, but no fees are being collected at this time.

The procedures for licensing HLW management facilities have not yet been determined. The Ministry of International Trade and Industry (MITI) and the Prime Minister's office (STA) have regulatory authority over commercial reactor licensing, and STA may receive the assignment for storage facilities and repositories. Procedures for public involvement in waste management have not been determined either, although formal public hearings similar to those for reactor licensing are expected. Financial incentives and door-to-door visits by utility and government officials have been used to obtain public acceptance of reactors in the past. In any event, the central government has the legal authority to override a local veto on siting of nuclear facilities.

4.3 Waste Management Strategy

Current policy is that all spent fuel will be stored at reactors for 2–3 years and then shipped offsite for reprocessing.[16] Japan now relies primarily on France and the UK for reprocessing services. The JNFS reprocessing plant to be built at Rokkashomura is planned to have a capacity of 800 MTU per year, just enough to handle the annual discharges from Japanese reactors currently expected for the mid-1990s. Careful consideration is being given to whether the contracts for reprocessing abroad would be extended after the year 2000. This may depend upon whether the current schedule for operation of the Rokkashomura plant in 1998 can be met. Slippages are possible, especially since there has been strong local opposition to the project. JNFS plans to construct a 3,000 MTU storage pool at Rokkashomura at the head-end of the reprocessing plant. This pool is planned to begin accepting spent fuel in 1994, four years ahead of the start of reprocessing. Since the projected rate of reactor discharges would fill that capacity in 4 years, the schedule is very tight.[17]

The HLW from reprocessing will be vitrified and stored for 30–50 years for cooling before geologic disposal. The first shipments of HLW from Europe are expected in 1990. The schedule for development of a permanent repository is relaxed. An underground research laboratory is planned for Horonobe, on Hokkaido, the northernmost island. This is not intended to be the repository site, however. Regulations for siting a repository are not expected to be developed until after 2000, and operation of the repository is not planned until after 2030.[18]

4.4 Interim Storage Policy in Detail

4.4.1 Interim storage: facilities and technologies

No independent spent fuel storage facility is planned in Japan. The only away-from-reactor spent fuel storage now contemplated is the 3,000 MTU pool planned as the front-end of the Rokkashomura reprocessing facility. Because there might be some need for at-reactor storage if domestic reprocessing is delayed and the foreign contracts are not renewed, the Central Research Institute of the Electric Power Industry (CRIEPI) is working on dry storage technology, and is currently participating in a 4-year exchange agreement with the Electric Power Research Institute (EPRI) in the U.S. on that subject. A particular focus of this effort is the possible use of nodular cast iron casks for transportation as well as storage.[19] Such casks have been licensed for both purposes in Germany but only for storage in the U.S., since the U.S. NRC has concerns about use of cast iron in transportation casks. Both Germany and Switzerland have selected cast iron storage/transportation casks for their central storage facilities. Cask storage is of most interest to CRIEPI because it allows storage capacity to be added in small increments as needed, with low initial capital investment. Transportable casks are of particular interest because the utilities are responsible for spent fuel transportation as well as on-site storage, and dual-purpose casks are believed to be most cost-effective when the costs of both functions are considered together.

Both returned HLW and the HLW produced at the Rokkashomura plant will be stored at that site. The relatively small amount of HLW produced at PNC's Tokai Mura plant will be stored at that facility.

4.4.2 Rationale for at-reactor/centralized storage decision

Since it is not clear at present that there will be a need for spent fuel storage capacity beyond that to be included as an integral part of the reprocessing plant, there has been no explicit decision about whether or not to expand at-reactor storage. Several factors may be relevant when and if such a decision must be made. The reactor sites are relatively small, and some may not have much capacity for storage outside of the pools. In addition, the owners of some power plants have committed to people living nearby to ship the spent fuel offsite for reprocessing as soon as possible.[20] Thus in some cases the option of new contracts with foreign reprocessors may be a more attractive way to deal with slippages in domestic reprocessing than dry storage at the reactor site.

4.4.3 Financial arrangements for storage

The cost of spent fuel and HLW storage at reprocessing plants is included in the cost of reprocessing.

4.4.4 Other roles for storage site

As noted, the only waste storage away from the reactor sites will occur at reprocessing facilities.

5.0 SPAIN

5.1 Status of Nuclear Power and Waste Management

Spain has ten nuclear reactors (about 7.4 GWe total capacity) that supply about 36 percent of the country's electricity.[21] A moratorium on new nuclear power plant construction has been in place since 1983.

The operating reactors are expected to discharge 1,500 MTU of spent fuel through the end of this century, and a total of about 5,500 MTU by 2035. Only fuel from the one GCR (Vandellos) is sent abroad for reprocessing by COGEMA. It is currently expected that the LWR spent fuel will be disposed of directly without reprocessing.

5.2 Institutional Structure of Reactor Operation and Waste Management

Spanish reactors are owned and operated by ten utilities. ENRESA, the state-owned National Waste Management Company created in 1984, is responsible for preparation, transportation, treatment, interim storage, and disposal of spent fuel and radioactive waste (including low- and intermediate-level waste), as well as for reactor decommissioning. ENRESA collects and manages a fee on both nuclear and non- nuclear electricity based on the estimated costs for decommissioning and for all spent fuel and waste management operations outside power stations. The Ministry of Industry and Energy controls ENRESA, reviews and approves the annual waste management plan prepared by ENRESA, and sets the waste management fee annually.

Regulatory review of nuclear facilities is exercised by the CSN (Nuclear Safety Council), which evaluates license applications and recommends government actions. Licenses for nuclear facilities are granted by the Minister of Industry and Energy, after consultation with the CSN and local authorities. During the licensing process, public hearings are held to solicit local opinion.

5.3 Waste Management Strategy

Spain plans for direct disposal of unreprocessed LWR fuel. A small amount (several cubic meters) of solidified HLW from French reprocessing of the Vandellos GCR fuel will also require disposal. There is no sense of urgency about final disposal. Because of the planned aging period for spent fuel and HLW, disposal is not expected to begin until around 2020. Site selection criteria for a repository will be completed by 1995, and candidate sites proposed to Federal authorities by 2000.

5.4 Interim Storage Policy in Detail

5.4.1 Interim storage: facilities and technologies

In 1987 the Government approved ENRESA's first radioactive waste management plan, including plans to develop a central storage facility for spent fuel. At that time, the facility was expected to begin operation in 1994. According to that plan, spent fuel would be stored at reactors for about 10 years, then moved to the central storage facility for a period of 40 years or more prior to final disposal. However, more recent studies of options for expanding reactor pool storage capacity have indicated that more time is available before the central facility is needed. The second radioactive waste management plan, approved in January 1989, does not contain a specific commitment to or schedule for a central storage facility. Instead, the plan indicates that there is sufficient time for the decision about the type and location of interim storage to ensure that there will be extensive experience in other countries with the system that is finally selected.[22]

Both wet and dry storage are under consideration, and no final decision has been made. ENRESA is currently supporting work by an American company (Nuclear Assurance Corporation) on the development and licensing of a transportable storage cask for possible use at the central facility and perhaps at reactor sites before shipment to central storage. Availability of such casks is seen as providing additional flexibility to the waste management program.

5.4.2 Basis for at-reactor/centralized storage decision

Two major benefits are cited for a centralized interim spent fuel storage facility. First, because of the extended schedule for permanent disposal, some reactors may require decommissioning before a repository is available to accept the fuel. While at-reactor storage is seen as satisfactory while the reactors are operating, ENRESA—which is responsible for decommissioning as well as spent fuel management—would prefer to have the fuel removed from the sites after shutdown. (For planning purposes, the current waste management plan assumes that dismantlement of reactors could begin 5 years after shutdown.[23]) Second, the central storage facility would provide a site for R&D on spent fuel, e.g. on encapsulation techniques for disposal.[24]

Because there is no pressure for early disposal, there has been no concern that availability of a central storage facility would delay the repository program.

5.4.3 Financial arrangements for storage

The cost of a central storage facility would be paid for from the fee collected by utilities from consumers of electricity.

5.4.4 Other roles for storage site

As noted, ENRESA hopes to use a central storage site for waste management R&D.

6.0 SWEDEN

6.1 Status of Nuclear Power and Waste Management

Sweden has 12 nuclear reactors (about 9.6 GWe total capacity) that supply about 50 percent of the country's electricity.[25] As a result of a national referendum on nuclear power in 1980, a parliamentary decision was taken to allow use of existing nuclear capacity but to phase out all nuclear plants by 2010 at the latest. The first unit is planned to be shut down in 1995. By the end of the nuclear power program in 2010, Sweden's reactors are projected to have produced about 7,800 metric tons of spent fuel which will be handled as waste.[26] Sweden has decided not to reprocess its spent fuel because it is not now economical to do so and because of nuclear proliferation concerns. Sweden is trying to sell the remainder of its existing reprocessing contracts.

6.2 Institutional Structure of Reactor Operation and Waste Management

In general, implementation of waste management is a responsibility of the waste generators, while regulation and oversight are a responsibility of the government. Swedish reactors are owned and operated by four utilities, one of which—the State Power Board—is government-owned. By law, the owners of nuclear power reactors have primary responsibility for all aspects of radioactive waste management, including both interim storage and disposal. The utilities are discharging this responsibility through the Swedish Nuclear Fuel and Waste Management Company (SKB), created by the utilities in 1972 and controlled by them. SKB is responsible for executing the spent fuel and waste management program for the Swedish utilities and manages waste disposal research and development facilities.

The ultimate and long-term responsibility for disposal lies with the Government, which supervises the planning, research and development for the waste management program and administers funding for waste management through the SKN (the National Board for Spent Nuclear Fuel). This funding is provided through a fee on nuclear electricity production that varies for each utility depending upon the waste mix it produces. The fee is recalculated annually.[27]

Regulatory responsibility for nuclear facilities is shared by the SSI (the National Institute of Radiation Protection) and the SKI (the Nuclear Power Inspectorate). The SSI sets and enforces basic radiation protection standards, while the SKI licenses, supervises, and controls safety of design, construction and operation of nuclear facilities. Any applicant for a license must obtain a site permit from the Government. The permit can be vetoed by the local municipal administration and must receive favorable recommendations from both SKI and SSI.

The local Community council can veto the location of nuclear facilities and only Parliament could overrule such a veto. Sweden provides no direct benefit for the local communities for accepting nuclear facilities. Some communities are antinuclear, while others view nuclear facilities more favorably because they provide jobs and other benefits to the local economies. Sweden has created local safety committees at each nuclear site to serve as liaison with officials at the nuclear facilities. The committees, which are supervised and funded by the government, are entitled by law to full information regarding nuclear activities.

6.3 Waste Management Strategy

Sweden's approach to waste management has been shaped by the 1977 Stipulation Law that linked initial loading of fuel in new reactors to a demonstration that each utility had either a plan for safe direct disposal of the spent fuel or a contract for reprocessing combined with a plan for safe disposal of the HLW.[28] This led to early signing of reprocessing contracts with France, and to rapid preparation of design studies to demonstrate the existence of concepts for safe disposal. Three studies (KBS-1, KBS-2, and KBS-3) were prepared, the first dealing with HLW and the latter two with direct disposal of spent fuel. They have been accepted by the government as adequately demon-

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strating that both HLW and spent fuel can be disposed of safely.

Although SKB contracted for foreign reprocessing of over 800 MTU of spent fuel, the government has announced that no additional reprocessing contracts will be signed. No plutonium recycle is now contemplated and direct disposal of spent fuel is planned. SKB is trying to sell the existing reprocessing contracts. Some reprocessing contracts have already been sold to Japan. Also, a small amount of fuel that was shipped for reprocessing has been swapped against German spent fuel with some West German utilities, to avoid the need of taking back reprocessing waste to Sweden. This was a one-time exchange of reprocessing waste for spent fuel that will not be repeated.[29]

In the reference waste management plan for direct spent fuel disposal laid out in KBS-3, spent fuel is normally stored on-site for at least 1 year in a spent fuel pool and then shipped by boat to a central interim storage facility, CLAB (described below). The fuel would remain at CLAB for 30 to 40 years before final disposal, because the resulting tenfold reduction in radiation and heat output would facilitate achievement of the relatively low maximum temperature (80°C, according to KBS-3) planned for the permanent repository. Based on these assumptions, Sweden's target date for developing a repository is currently the year 2020. The shortest possible storage period is about 15 years from the date a decision is made, because of the time it would take to find a site and build a repository. A shorter storage period would require a reduction in the amount of waste contained in each canister to keep the same target temperature level.

6.4 Interim Storage Policy in Detail

6.4.1 Interim storage: facilities and technologies

The CLAB plays the principal role in spent fuel storage in Sweden. At-reactor storage serves only to provide a relatively short cooling period before spent fuel is shipped to CLAB. Limited lifting capabilities at reactors prevented realization of the increased shipping cask capacities that a longer period of at-reactor storage would allow. Some of the pools in Sweden have high density racks but the newer reactors have less pool capacity because of the availability of the central interim storage facility.

A Parliamentary Commission recommended in 1976 that a central interim storage facility be built. The Commission recommended that the facility be located in an underground cavern and that a sea transportation system be developed. The decision to build the central interim storage facility was made in 1978. CLAB was built near the Oskarsham Nuclear Plant, a coastal location suitable for sea transportation from other Swedish reactors, which are also located on the coast. CLAB began receiving fuel in 1985.

CLAB is a wet pool storage facility. At the time CLAB was designed, Sweden was aware of dry cask storage but the technology was not well developed. As a result, dry cask storage was not seriously considered.[30]

The storage building is located underground in a rock cavern whose ceiling is 25 to 30 meters below ground level. CLAB has sufficient capacity to store 3,000 metric tons of fuel—all of the fuel generated by Sweden's 12 existing reactors until the mid-1990s. Expansion will be needed to hold the 7,800 metric tons that would be generated by those reactors if they operate to 2010. CLAB was built in such a way as to facilitate such expansions.

The facility was built to minimize the doses to personnel. In actual operation, the doses have been only 25 percent of those that had been calculated. In 1987, for example, the average dose was about 110 millirem per worker. The total dose to workers in that year was about 6.8 manrem, or about 25 millirem per MTU of spent fuel received at CLAB during the year (272 MTU).[31]

6.4.2 Basis for at-reactor/centralized storage decision

The Parliamentary Commission that considered spent fuel storage options focused on what approach to central storage should be taken, not whether there should be a central storage facility. At the time the study was performed, dry storage was not thought to be a readily-licensable option, so the only approach to expanding at-reactor capacity was thought to be construction of new pools. This was not considered a practical option, particularly in view of the limited space at the reactor sites.[32]

Siting was not a problem, since the local community welcomed the CLAB facility because it provided jobs and because there seemed to be consensus that it is the country's responsibility to handle its own wastes. There was no opposition to CLAB based on concerns that availability of a storage facility might lead to deferral of disposal. Indeed, some environmental groups favor continuous monitored storage because they believe it is not yet possible to safely and permanently dispose of the waste.

6.4.3 Financial arrangements for storage

CLAB is paid for from the waste disposal funds. Costs of the facility are allocated among the utilities according to the amount of spent fuel they will send to it.

6.4.4 Other roles for storage site

There are no current plans to use the CLAB site for any other waste management purposes.

7.0 SWITZERLAND

7.1 Status of Nuclear Power and Waste Management

Switzerland has five nuclear reactors (about 2.9 GWe total capacity) that supply about 38 percent of the country's electricity.[33] Three others were planned but later cancelled mainly because of extensive public opposition. In any case, it was less expensive to purchase power from France. No new nuclear power plants are planned for at least the next 10 years.

A total of about 2,000 MTU of spent fuel is expected to have been discharged through the end of this century. Fuel is currently stored in reactor pools, and pool capacity is expected to be adequate through the mid-1990s. Swiss utilities currently purchase reprocessing services from France and the UK. It is expected that shipments of vitrified HLW from that reprocessing may begin in 1993. Recycling of separated plutonium in LWRs is practiced already on a pilot scale.

7.2 Institutional Structure of Reactor Operation and Waste Management

Swiss reactors are owned and operated by five utilities. The utilities are responsible for storing spent fuel, vitrified HLW, and other reprocessing wastes until disposal capacity is available. To meet storage needs in the late 1990s, the utilities initially formed the Consortium d'Etudes Lucens (CEL) to plan a centralized interim storage facility for spent fuel and returned HLW to be located at the site of a research reactor at Lucens. When this project was dropped for reasons discussed below, a new organization, Zwischenlager Gesellschaft (Intermediate Storage Company), was formed to develop a storage facility at another site in Wuerenlingen.

All producers of radioactive waste are also responsible for its safe disposal, although the government is permitted to take over this responsibility with utilities funding the activities if the utilities are not able to take care of the problem themselves. The National Cooperative for the Disposal of Radioactive Waste (NAGRA/CEDRA), formed by the waste producers including the federal government, currently has responsibility for developing disposal facilities. The costs of the activities of NAGRA, and the future costs of repository construction, are included in the charge for electricity. The utilities accumulate reserves for ultimate disposal, while NAGRA handles funds for R&D on disposal.

The Swiss Department of Energy is responsible for setting the standards and the Government is responsible for licensing nuclear power plants and facilities for the interim storage and disposal of nuclear wastes. Cantons have a land use veto over water use, zoning, and construction permits, but may not use this power arbitrarily to block nuclear projects. Such projects must be treated the same as all others. Conflicts between the Federal government and local governments (cantons) may be settled by a Federal tribunal. Ultimately, the Federal government has the right to assist the development of waste disposal facilities through expropriation of land, and can transfer that right to NAGRA.

7.3 Waste Management Strategy

Reprocessing with recycling of plutonium and uranium in thermal reactors is the current Swiss strategy for the back end of the fuel cycle, and contracts for reprocessing in France and England cover all the spent fuel to the mid-1990s. When these contracts expire, the Swiss will reexamine whether reprocessing shall continue. The option of direct disposal of unreprocessed spent fuel is open, but no project is now being conducted to develop this option.

The first solidified HLW can be returned from France in 1993. This waste and any unreprocessed spent fuel that cannot be accommodated in reactor pools will be stored in a central facility until eventual reprocessing or final disposal. The period of storage for both spent fuel and HLW is planned to be about 40 years after the spent fuel (disposed of directly or reprocessed to produce HLW) is discharged from the reactor. This storage period is planned to reduce the heat load and temperature in the final repository and to allow time for siting a repository.[34]

A 1978 revision to the Atomic Energy Law provided that no new reactor licenses may be issued unless it can be demonstrated that safe disposal of the radioactive wastes produced by the plants is feasible. Since there were no new plant orders, this statute did not put much pressure on the development of a final disposal solution. Therefore, the Department of Energy conditioned the utilities' licenses for their nuclear power plants to require that safe disposal be demonstrated by December 1985 or the licenses would be revoked. NAGRA was requested to conduct the demonstration. The resultant study was called Project Gewaehr (Guarantee). The 6-year study, completed in 1985, concluded that a repository for HLW was feasible with present-day technology. A 6-year review of the study by government safety authorities, with input from foreign experts, concluded that Project Gewaehr had provided adequate proof that safe disposal for HLW was achievable, but that no specific site had been shown to be acceptable for a repository.

With a planned 40 year aging period for spent fuel and HLW, disposal is not expected to begin until after 2020. Despite this relaxed schedule for operation of a repository, Project Gewaehr led to a firm policy decision that there must be a significant continuous effort towards its development.[35] The next step required after Project Gewaehr's conceptual demonstration of existence of a disposal solution is site characterization to identify precisely where in Switzerland the concept could be implemented. One or two sites are to be selected for characterization from the surface during the 1990s, with sinking of a shaft and construction of an underground research laboratory at one site early in the next century. (An underground research laboratory is already in operation at Grimsel, but this facility is not intended to be developed into a repository.) A decision whether to proceed with development of a Swiss repository or to participate in a foreign repository will be made around the year 2000. If the domestic repository option is selected, a license application would be submitted in 2010, with operations to begin by 2025.

7.4 Interim Storage Policy in Detail

7.4.1 Interim storage: facilities and technologies

Spent fuel is stored on-site at the reactors until it is shipped to a reprocessing facility in France or the U.K. All plants have the capacity for 7 to 12 years of buffer storage over a full core reserve. The older plants only had about 3 years of buffer capacity but they have reracked to create additional storage capacity.

As noted, a central storage facility is planned to handle both returned HLW and spent fuel not subject to reprocessing contracts. The facility is to be sited in Wuerenlingen (siting questions are discussed further below). Plans for the proposed facility call for dry storage of 1,555 MTU of spent fuel or 550 cubic meters of vitrified HLW (from reprocessing 4,968 MTU of spent fuel) in 184 Castor-type transportation/storage casks. The planned design is very similar to Gorleben, with the casks to be placed in a building for shielding and safeguards considerations (for spent fuel). The initial capacity is sufficient for 15–20 years' accumulation, while the storage facility will be designed to have enough capacity to store 60 years of HLW if the Swiss continue to reprocess the spent fuel and to store 30–35 years of spent fuel if reprocessing is discontinued. It is also hoped that a waste treatment facility, including advanced compaction facilities and an incinerator for organic materials and resins, will be located on the same site.

In selecting a storage technology, the Swiss considered storage in casks with passive cooling and three options involving active cooling: pools, concrete bunkers, and modular bunkers. They selected dry cask storage because it involved the lowest initial investment costs; it was flexible enough to handle either spent fuel or HLW; it required only passive cooling; and it could meet the safety standards, e.g., withstanding an airplane crash. The ability of cask storage to add capacity in very small and relatively inexpensive increments as needed was seen as particularly important in view of the small volumes of waste involved. Use of transportable storage casks also left open the option of at-reactor storage in the event of difficulties in siting a central facility.

7.4.2 Basis for at-reactor/centralized storage decision

The Swiss considered both decentralized storage at the reactor sites and a centralized storage facility as options for interim storage of the HLW when it is returned from France and the U.K. Several factors appear to have been important in the selection of the centralized option.[36] It was felt that it was easier to do everything associated with providing an interim storage facility just once at a single central site than to do it four times at the four reactor sites. It was recognized that a decentralized approach would allow existing crews to be used, but overall the centralized approach was seen as a more optimized system. A related consideration was the idea of using the site for other waste facilities and activities, such as a low-level waste incinerator and a waste conditioning plant. This would provide a centralized back end of the fuel cycle.

Licensing issues were also a consideration. Some restrictions in existing permits prohibit the storage of wastes from more than one plant at any plant site, and it would be difficult to try to divide the waste stream from abroad in such a way that each site only received the waste from reprocessing the spent fuel generated at that site. On the other hand, some licensing considerations may favor a decentralized approach. Utilities interpret their permits as requiring only a license amendment instead of a new license if the waste is placed within the existing boundaries of the plant site, although some disagree with that interpretation. Licensing a centralized facility at a new site involves two phases—a construction permit and an operating license proceeding—which provides more opportunities for intervention in opposition to the facility.

Centralized storage was not seen as providing any significant financial advantages over decentralized storage. A centralized storage facility would require purchase of land, which is very expensive in Switzerland, and would involve a longer licensing process. However, locating a waste treatment plant at the same site would allow some cost savings with regard to the fuel handling crews. On balance, cost does not appear to have been an important factor.

When the decision was made that a centralized facility was the preferred option, the difficulty of licensing new sites for nuclear activities favored an initial effort to site the facility within the cave used by a decommissioned research reactor at Lucens. It was hoped that the existing site license would be sufficient, and that a new license would not be required. When it became clear that a new license would be necessary because the storage facility would require new surface facilities, and that there was strong local opposition, the site was dropped. The utilities then adopted a two-track approach: plan for the possibility of at-reactor storage and seek a new site for a central facility.

Following the at-reactor track, the Benzau I plant is applying for a license amendment now to expand on-site storage because it is running out of room in the pool. This expansion may be necessary now even if the effort to site a central facility is ultimately successful because of the time delay involved. If they build additional capacity they plan to build enough storage capacity to last for the life of the plant.

Meanwhile, a site at Wuerenlingen has been selected for the second attempt to develop a central storage facility.[37] This site has a number of advantages. Three of the five Swiss reactors are within 20 kilometers of the site, and the other two are within 100 kilometers. In addition, Wuerenlingen is the location of a national institute for nuclear research (the Paul Scherrer Institut), where some waste treatment and conditioning activities including incineration are already conducted. Thus the proposal to include a new incinerator and waste conditioning facilities at the storage site was not expected to raise major new issues and concerns with the local population.

A license application for the Wuerenlingen site has not yet been submitted because of local opposition to the project. The safety of the facility does not appear to be the source of concern. Rather, the municipality in which the site is located wants some direct payment from the utilities for accepting a facility that is not wanted by other communities. On June 23, 1989, the local assembly in Wuerenlingen met to consider whether to approve a zoning plan designed to prohibit construction of the facility or whether to allow the facility to proceed subject to the terms of an agreement that had been accepted by both the local council and the utilities. The agreement included several important provisions. First, it provided for annual payments to the community by the utilities. Second, it afforded the community some direct oversight of the facility by giving it one seat on the board of directors. Finally, it limited the period of storage to 25 years, at which time the agreement would have to be renegotiated. If the community decided at that time not to agree to further storage, the waste in storage at the site would have to be removed within 10 years. This provision was explicitly intended to ensure that storage remains only an interim solution.

By a large margin, the assembly rejected the zoning plan and approved the agreement. However, it is likely that opponents will be able to call for a full referendum on both propositions, which might not occur until the fall. Submission of a license application for the facility will probably await the results.

7.4.3 Financial arrangements for storage

The utilities will share the costs of developing and operating the central storage facility. Each utility will also pay the cost of the casks used to store its own fuel at the facility.

7.4.4 Other roles for storage site

As discussed above, the site is intended to become a center for a wide range of waste management activities, many of which are already conducted at the Wuerenlingen site of the nuclear research institute. Responsibility for all these activities would transfer to the Zwischenlager Gesellschaft, making a single organization at a single site responsible for the management of all radioactive wastes prior to disposal.

8.0 UNITED KINGDOM

8.1 Status of Nuclear Power and Waste Management

The United Kingdom (U.K.) has 41 power nuclear reactors—26 gas cooled (MAGNOX) reactors, 14 advanced gas-cooled reactors (AGRs), and one breeder reactor. These reactors represent about 12 GWe total generating capacity, and produce about 17 percent of the UK's electricity. The UK is planning construction of four new PWR nuclear stations totalling 4.4 GWe between 1990 and 2000.[38] Work on the first (Sizewell B) has started.

Spent fuel, including some of foreign origin, has been reprocessed at the Sellafield plant (formerly Windscale) since 1952. Plutonium from British sources is used in the Dounreay prototype breeder reactor or is stored for future use in breeders and thermal reactors. A large new plant for reprocessing thermal oxide fuel (THORP) is under construction at Sellafield. High-level waste will be vitrified at the Sellafield site and stored there for at least 50 years before eventual disposal.

8.2 Institutional Structure of Reactor Operation and Waste Management

Although electricity generation is a nationalized industry in the U.K., it is currently being privatized. The two major utilities are the Central Electricity Generating Board (CEGB) and the South of Scotland Electricity Board (SSEB). The former reports to the Secretary of State for Energy, the latter to the Secretary of State for Scotland. Both are responsible for managing spent fuel until it is shipped to Sellafield. British Nuclear Fuels plc (BNFL) is responsible for storing and reprocessing the fuel at Sellafield, and for storing the resulting HLW until disposal. BNFL reports to the Secretary of State for Energy.

A national company, U.K. NIREX, Ltd., was established in 1982 to site, build, and operate repositories for low- and intermediate-level wastes. Efforts to develop a repository for HLW have been deferred indefinitely, and it is not clear whether NIREX will ultimately have that responsibility. The U.K. Department of the Environment (DoE) is responsible for waste management policy and for research on HLW disposal, which is contracted primarily to the British Geologic Survey and the U.K. Atomic Energy Authority (now known as AEA Technology). Since the waste producers are all government-owned organizations, provisions are made in their budgets for waste management costs. There is currently no separate waste fund or fee on nuclear-generated electricity.

The DoE is responsible for approving licenses for waste management activities. Her Majesty's Nuclear Installation Inspectorate, part of the Health and Safety Executive which was established by Act of Parliament, is responsible for performing independent assessments of the safety of the electricity generating boards' activities. The central government has the legal authority to override local vetoes of siting decisions, but this is not done lightly.

8.3 Waste Management Strategy

Current planning is that all MAGNOX spent fuel will be reprocessed, and most is stored at reactor sites in pools for a year or less before shipment to the reprocessing plant. Most of the oxide fuel from the AGRs is being stored in pools at Sellafield until completion of the new thermal oxide reprocessing facility (THORP). While CEGB has a major commitment with BNFL to reprocess spent fuel, consideration is being given to deferring reprocessing and storing the fuel for an extended period.[39] To date, commitments have been made to reprocess only 1850 MTU of AGR fuel. The question of possible direct disposal of spent fuel has not been dealt with yet.

HLW is now stored in liquid form at Sellafield. It will be solidified following completion of a vitrification plant (using a French process) now under construction there. The solidified waste will be stored at Sellafield for at least 50 years before ultimate geologic disposal. This policy of extended storage and deferred efforts to site a repository was adopted in late 1981 following intense local opposition to a drilling program associated with field research for a HLW repository.[40] The focus of the U.K.'s geologic research program is now on confirming the applicability to the U.K. of other countries' research.

8.4 Interim Storage Policy in Detail

8.4.1 Interim storage: facilities and technologies

MAGNOX fuel is usually shipped to Sellafield for reprocessing after no more than a year of storage in the reactor pool because the fuel cannot be wet-stored for very long. However, there is a dry vault storage facility at the Wylfa power station for its MAGNOX fuel. The original equipment, installed in 1964, consisted of three 80 MTU modules; additional facilities, each with a capacity of 350 MTU, were added in the late 1970s. (A similar design, applicable to LWR fuel and HLW, was submitted by GEC Energy Systems to the U.S. NRC as a Topical Report and was approved in 1988.)

The AGRs have onsite pool storage capacity for only a total of about 2 years of operation. They are dependent on shipping fuel to Sellafield within that period, for storage there in pools until the THORP plant begins operating. CEGB announced last year that it plans to build a dry vault storage facility for AGR fuel at the Heysham site, which is the location of four reactors.[41] This will allow fuel not covered by current reprocessing contracts with BNFL to continue to be shipped offsite in a timely manner, while at the same time allowing decisions about reprocessing that fuel to be deferred. The facility will allow storage capacity to be added in modules of 210 MTU. The facility will begin with four modules and can be expanded to up to 30 modules, or about 6000 MTU. Cask storage was considered but rejected because of cost.

The PWRs are being built with much greater storage capacity than the AGRs—probably more than 20 years taking into account likely increases in burnup. Because of the leeway that this storage capacity provides, the current position is that no decision about the management of the PWR spent fuel has to be made at this time.

8.4.2 Basis for at-reactor/centralized storage decision

The CEGB has not yet publicly stated its arguments for the decision in favor of a centralized site for storage for AGR fuel. However, economic considerations appear to have been an important factor. Because AGR fuel is encased in stainless steel, it requires very thorough drying before storage in order to avoid corrosion. That in turn requires a head-end facility for drying the fuel and sealing it into containers. This facility (which would be required even with cask storage) represents a significant part of the total cost of storage. As a result, there are economies of scale in constructing only one such facility at a central site.

The full case for the decision may be made public in the Public Inquiry that is likely to result from submission of an application for planning permission for use of the site for the storage facility. Local reaction to the decision has been strong, and concerns about how long the fuel might be left there have been expressed, but the facility has not become a national issue.

8.4.3 Financial arrangements for storage

The AGR storage facility will be a joint venture of the CEGB and SSEB, but no financial details are publicly available.

8.4.4 Other roles for storage site

As noted, Heysham is already the site of four reactors. No other waste management activities are planned for the site.

9.0 CONCLUSIONS

1. The eight countries show great diversity in their institutional and political environments for nuclear power and waste disposal. None mirrors the U.S. situation very closely. All have substantially less nuclear power generation (and resulting waste) and far fewer waste producers to deal with than does the U.S. On the other hand, in six of the eight countries, nuclear power represents a larger—in some cases, much larger—relative share of the country's electricity generation than the approximately 20 percent in the United States. (See Tables D1 and D2.)

2. The countries vary widely in their reprocessing policies. Five plan to reprocess some or all of their spent fuel; two have decided not to reprocess; and one (Canada) has made no firm decision. (See Table D1—Reprocessing.)

3. Reprocessing has in the past allowed some of the countries to avoid having to make decisions about spent fuel storage. However, because the economics of reprocessing are not now favorable, some of the countries that are currently reprocessing fuel are using spent fuel storage as a way to defer early commitments to further reprocessing. In several of countries that are reprocessing fuel, direct disposal of spent fuel is now considered an option.

4. All eight countries plan on disposal of HLW or spent fuel in a geologic repository, and are engaged in some phase of the scientific investigations needed to develop such a repository.

5. The pace of repository development in these countries is not driven by any perceived urgency to demonstrate the existence of a disposal facility or to dispose of waste. While two countries (Sweden and Switzerland) have laws linking operation of nuclear powerplants to a demonstration of the existence of a safe method for disposing of the waste, these laws required only a conceptual demonstration rather than actual siting and operation of a disposal facility. In general, deferred disposal is viewed as beneficial because it reduces the heat output of the waste. Only West Germany plans to have a repository before 2010, and that country has no plans for rapid disposal. (See Table D1—Repository Schedule.)

6. Centralized facilities for storage of spent fuel and/or HLW have been built or are planned (at reprocessing plants or other sites) in all but one country. Only in Canada, with most reactors located at a few multiple-reactor sites, does it appear that at-reactor spent fuel storage might be the preferred option, although no decision has yet been made. (See Table D1—Sites.)

7. While there have been local concerns raised about the length of storage at a central storage facility in some cases, this has not become a national issue in any of the eight countries as it has in the United States. In particular, opposition to storage facilities on the grounds that they may reduce the incentive to develop a permanent repository does not appear to have been a major factor in the storage decisions in any of the countries.

8. Transportable storage casks appear to be the favored modular dry storage option. Two countries have already selected transportable storage casks for their central storage facilities, and three others are developing or eval-

Table D1 — Summary Table: Spent Fuel and HLW Storage in Eight Countries

COUNTRY	NUCLEAR CAPACITY (% ELECTR GEN.)	REPRO-CESS-ING	INTERIM STORAGE: SITES	INTERIM STORAGE: METHODS	INTERIM STORAGE: TIME	INSTITUTIONAL RESPONSI-BILITY[e]	PUBLIC RESPONSE	REPOS-ITORY SCHED-ULE
CANADA	11 GW (13%)	No[a]	Reactor Sites	Wet Pools, Perhaps Dry Casks[d] at Pickering	>20 Yrs	Utilities	No Effort Yet to Site a New Storage Facility	>2010
FRANCE (FR)	53 GWe (70%)	Yes	Reactor Sites	Wet Pools	~1 Yr	EDF	Little Apparent Public Concern	>2010
			Reproc. Plants	SF—Wet Pools HLW—Dry Vaults	~2 Yrs >20 Yrs	Cogema		
FEDERAL REPUBLIC OF GERMANY (FRG)	23 GWe (40%)	Yes (Frg, Fr Uk)	Reactor Sites	Wet Pools	3-10 Yrs	Utilities	Strong Opposition to Siting Interim Storage Facilities	~2008
			Indep. Facility (Gorleben, Ahaus)	SF—Dry Casks[c] HLW—Dry Casks[c]	Undecided >10 Yrs	Utilities (Thru BLG)		
JAPAN (JA)	28 GWe (32%)	Yes (Fr Ja)	Reactor Sites	SF—Wet Pools[c]	2-3 Yrs	Utilities	Strong Opposition to New Reprocessing Plant Where SF and HLW will be Stored	>2030
			Reproc. Plantes	SF—Wet Pools HLW—Undecided	~4 Yrs 30-50 Yrs	Utilities (Thru JNFS)		
SPAIN	7 GWe (36%)	No	Reactor Sites	Wet Pools	Undecided	Utilities	No Effort Yet To Site a New Storage Facility	~2020
			Indep. Facility (Not Sited)	Pools and/or Dry Casks[b]	Undecided	Govt Corp. (Enresa)		
SWEDEN	10 GWe (50%)	N0	Reactor Sites	Wet Pools	~1 Yr	Utilities	Little Apparent Local Opposition to CLAB	>2020
			Indep. Facility (Clab, at Oskersham Reactor Site)	Wet Pools	15-40 Yrs	Utilities (Thru SKB)		
SWITZERLAND	3 GWe (38%)	Yes (Fr, Uk)	Reactor Sites	Wet Pools	<12 Yrs	Utilities	Local Opposition to Storage Facility addressed Through Payments to Community, 25 Yr Limit on Operation Subject to Renegotiation	>2025
			Indep. Facility (Wurenlingen) HLW, SF not Under Reproc. Contract	SF, HLW—Dry Casks[c]	~40 Yrs	Utilities (Thru Zwischenlager Gesellschaft)		
UNITED KINGDOM (UK)	12 GWe (17%)	Yes	Reactor Sites	Wet Pools	~1 Yr	Utilities	Local Concern About Storage Facility Planned For Heysham Reactor Site	>2030
			Indep. Facility For AGR Fuel (at Heysham Reactor Site)	SF—Dry Vault	Undecided	Utilities (Joint Venture)		
			Reproc. Plant	SF—Wet Pools HLW—Dry	Few Yrs >50 Yrs	BNFL		

[a] No decision about future reprocessing has been made.
[b] Transportable storage casks are under development and are the favored storage technology.
[c] Existing transportable storage casks have been selected for the storage facility.
[d] Utilities are investigating transportable storage casks for buffer storage.
[e] Utilities may be private, government, or joint industry-government entities.

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Table D2: Spent Fuel Storage in the United States

COUNTRY	NUCLEAR CAPACITY (% ELECTR GEN.)	REPRO-CESS-ING	INTERIM STORAGE SITES	INTERIM STORAGE METHODS	INTERIM STORAGE TIME	INSTITUTIONAL RESPONSI-BILITY	PUBLIC RESPONSE	REPOS-ITORY SCHED-ULE
UNITED STATES	99 GWe (20%)	No	Reactor Sites	Wet Pools, Dry Modules	Undecided	Utilities	Strong Opposition to Federal Storage and MRS Siting Effort	>2003

uating the technology for later use. (See Table D1—Interim Storage/Methods.)

9. In summary, the experience of these countries provides useful insights, but does not have any single clear message for U.S. spent fuel storage policy. The U.S. must make its decisions in a situation that is very different in a number of important aspects: in the absolute size (much larger) and relative importance (generally smaller) of its nuclear power program; in the regulatory, institutional, and political environment for nuclear power and waste management; in the pressures to develop a permanent repository and the related concerns that central storage facilities would delay that goal; and in the geographic characteristics (e.g. transportation distances, population densities, and the range of options available for siting storage and disposal facilities) that must be taken into account in waste management policy.

10.0 SOURCES

Principal Sources: This report summarizes information supplied to JK Research Associates by the MRS Review Commission, supplemented by telephone interviews with individuals associated with the nuclear power or waste management programs of each of the eight countries.

10.1 Material supplied by MRS Review Commission

There were two main sources of information provided by the Commission:

a. The trip report on the Commission's visits to waste management facilities in France, West Germany, Sweden, and Switzerland, prepared by the Commission's executive director, Jane A. Axelrad: *Trip Report—Visits to European Waste Management Facilities, October 17–28, 1988,* Memorandum to the Monitored Retrievable Storage Review Commission, September 3, 1989. This memorandum is the principal source of information in the sections dealing with the four countries it describes.

b. Briefing materials on waste management programs in the eight foreign countries provided by the U.S. Department of Energy (DOE) to the MRS Review Commission. Information about the four European countries visited by the Commission is contained in a *MRS Review Commission Briefing Package for European Fact Finding Trip,* dated October 1988. This will be referred to as *Briefing Package* in references. Information on Japan, Canada, Spain, and the United Kingdom was provided by the DOE separately on June 7, 1989. This material, referred to as *Additional Information* in references, is the principal source of information on the status of nuclear power and the related institutional structure contained in the sections dealing with the four countries it covers.

10.2 Interviews

The following individuals were the principal sources of additional information for this report. Dates of the interviews are shown; in some cases there were additional brief discussions. A draft of the section of the report dealing with each country was also reviewed by one or more of the individuals contacted concerning that country.

Canada:	Dr. William Hancox, AECL/WNRE, 6/26/89.
	Dr. Colin Frost, Ontario Hydro, 6/26/89.
France:	Ms Cheryl A. Hutchison, NUMATEC/ COGEMA (Bethesda, MD office), 6/29/89.
Germany:	Dr. Klaus Einfeld, DWK, 6/26/89.
Japan:	Dr. Toshiari Saegusa, Central Research Institute of the Electric Power Industry (CRIEPI), 6/29/89.
	Mr. Masami Katsuragawa, PNC (Japan), 6/20/89, 6/22/89.
Spain:	Mr. Jose Gravalos, ENRESA, 6/26/89.
Sweden:	Mr. Torsten Eng, SKB, 6/21/89.
Switzerland:	Mr. Hans Issler, President, NAGRA, 6/26/89.
	Mr. Charles McCombie, NAGRA, 6/22/89.
U.K.	Mr. Thomas McInerney, Managing Director, U.K. Nirex, Ltd., 6/22/89.
	Dr. Peter Wilmer, Central Electricity Generating Board, 6/27/89.

11.0 REFERENCES

1. Information on nuclear power generation provided by Dr. Colin Frost of Ontario Hydro. Spent fuel projections assume a 40 year reactor life and an additional 4-unit station of the Darlington design.

2. Information on the spent fuel storage research program provided by Dr. Colin Frost, Ontario Hydro.

3. USDOE, *Final Version Dry Cask Storage Study,* DOE/RW-0220, Washington, D.C., February 1989, p. I-75.

4. Information provided by Cheryl Hutchison, NUMATEC/COGEMA.

5. Information on the German nuclear power program provided by Dr. Klaus Einfeld, DWK.

6. International Energy Associates Limited (IEAL), *Regulatory Strategies for High-Level Radioactive Waste Management in Nine Countries,* IEAL-R/87-93, Fairfax, Virginia, December 1987, p. 3-1.

7. Interview with Dr. Klaus Einfeld, DWK.

8. Interview with Dr. Klaus Einfeld, DWK.

9. Karlsruhe Nuclear Research Center Ltd., *Systems Study—Alternative Entsorgung,* Final Report Executive Summary, KWA 2190/1, Karlsruhe, FRG, March 1985, p. 24.

10. Ibid.

11. Information on the status of storage facilities provided by Dr. Klaus Einfeld, DWK.

12. USDOE, *MRS Review Commission Briefing Package for European Fact Finding Trip,* Washington, D.C., October 1988, p. GE.4. Referred to hereafter as *Briefing Package.*

13. Interview with Dr. Klaus Einfeld, DWK.

14. Information supplied by Dr. Toshiari Saegusa, CRIEPI.

15. IEAL, *Regulatory Strategies,* p. 5-1.

16. Ibid., p. 5-7.

17. Information on status of Rokkashomura plant provided by Dr. Toshiari Saegusa, CRIEPI.

18. USDOE, Additional Information provided to the Monitored Retrievable Storage Review Commission, Washington, D.C., June 7, 1989, p. JA.3. Referred to hereafter as *Additional Information.*

19. Information on the storage technology research program supplied by Dr. Toshiari Saegusa, CRIEPI.

20. IEAL, *Regulatory Strategies,* p. 5-3.

21. U.S. Council for Energy Awareness (USCEA), *USCEA 1988 International Reactor Survey,* Washington, D.C., January 1, 1989.

22. Ministerio de Industria y Energia, *Segundo Plan General de Residuos Radioactivos,* Madrid, Spain, January 13, 1989, p. 14.

23. Ibid., p. 17.

24. Interview with Jose Gravalos, ENRESA.

25. USCEA, *1988 Survey.*

26. USDOE, *Briefing Package,* p. SW.9.

27. USDOE, *Briefing Package,* p. SW.6.

28. The Stipulation Law and its consequences are discussed in IEAL, *Regulatory Strategies,* pp. 6-5–6-6.

29. Information provided by Torsten Eng, SKB.

30. Interview with Torsten Eng, SKB.

31. Information supplied by Torsten Eng, SKB.

32. Interview with Torsten Eng, SKB.

33. USCEA, *1988 Survey.*

34. IEAL, *Regulatory Strategies,* p. 7–9.

35. Interview with Hans Issler, NAGRA.

36. Information on the storage decision obtained from interviews with Hans Issler and Charles McCombie, NAGRA.

37. Information on the status of the Wuerenlingen site provided by Hans Issler and Charles McCombie, NAGRA.

38. Information supplied by Dr. Peter Wilmer, CEGB.

39. IEAL, *Regulatory Strategies,* p. 8-7.

40. The controversy about the drilling program, and the subsequent shift in strategy, are discussed in IEAL, *Regulatory Strategies,* pp. 8-8–8-9.

41. Information on AGR and PWR storage plans provided by Dr. Peter Wilmer, CEGB.

Appendix E
Contractor Assistance

Contractors performed specific tasks to augment the Commission's technical work.

EBASCO Services, Inc. of New York, New York examined at-reactor storage needs and the costs, risks, and benefits of rod consolidation. The company provided estimates of at-reactor storage, evaluated storage capacity by individual facilities, compared differences between pressurized water reactor (PWR) and boiling water reactor (BWR) pool limitations, evaluated the impact of using various pick-up rules, and compared at-reactor storage needs under different interim storage configurations.

Golder Associates, Inc. of Redmond, Washington provided the Commission with a cost simulation model, the Nuclear WAste Cost Data Base and SimUlation Model (WACUM), designed to estimate the costs of various interim storage strategies, in particular the Department of Energy's cost estimates. In addition, Golder quantified the safety and environmental impacts of alternative spent fuel management strategies, and analyzed non-cost factors involved in determining MRS need on a quantitative basis.

ICF Technology Incorporated assessed the need for an MRS facility from a transportation perspective, using historical and technical analysis. The company designed the MRS Review Commission's Analysis of System Risk and Cost (MARC), which was used to evaluate the transportation and systems aspects of alternative spent fuel management strategies. ICF also reviewed, evaluated, and provided additional data to supplement the Golder study on Safety and Environmental Impacts for Alternative Spent Fuel Management Strategies.

A list of the contractor reports submitted to the Commission follows. Copies of these reports may be obtained from the MRS Review Commission until December 31, 1989. After December 31, 1989, copies of these reports will be on file at the Department of Energy in Washington, D.C., the Nuclear Waste Technical Review Board, Washington, D.C., the Alexander and Jean Heard Library, Vanderbilt University, Nashville, Tennessee 37235 and the College of Engineering Library, University of Texas at Austin, Austin, Texas 78712.

List of Contractor Reports

EBASCO Services, Inc.

"Rod Consolidation Costs, Risks and Benefits," June 1989, Two World Trade Center, New York, NY 10048.

"Spent Fuel Storage Need and At-Reactor Capability Study," June 1989, Two World Trade Center, New York, NY 10048.

"Reactor Specific Spent Fuel Database and Storage Projection Model Documentation Report," June 1989, Two World Trade Center, New York, NY 10048.

GOLDER Associates, Inc.

"Cost Estimate for Interim Storage Facilities," October 1989, by I. Miller, 4104 148th Avenue, NE, Redmond, Washington 98052.

"Interim Spent Fuel Management Cost Data Base," Project No. 893-1032.120, June 1989, by W. Dershowitz, C. Breeds, W. Roberds and I. Miller, 4104 148th Avenue, NE, Redmond, Washington 98052.

"Quantitative Evaluation of MRS Non-Cost Factors," Project No. 893-7028, June 1989, 1451 Harbor Bay Parkway, Suite 1000, Alameda, California 94501.

"Safety and Environmental Impacts for Alternative Spent Fuel Management Options," July 1989, 1451 Harbor Bay Parkway, Suite 1000, Alameda, California 94501.

"ISFM Cost Estimate Data Base Application User's Guide—Version 1.1," Project No. 893.1032.110, June 1989, by M. Feuer, C. Breeds and W. Dershowitz, 4104 148th Avenue, NE, Redmond, Washington 98052.

"WACUM Versus DOE Systems Study Comparison," Project No. 893-1032.250, September 1989, 4104 148th Avenue, NE, Redmond, Washington 98052.

"WACUM: Nuclear Waste Cost Database and Simulator Model—User's Guide Version 1.13," Project No. 893-1032.210, June 1989, by I. Miller and W. Fuget, 4104 148th Avenue, NE, Redmond, Washington 98052.

"WACUM Version 1.10 Users Guide," Project No. 893.1032.210, June 1989, 4104 148th Avenue, NE, Redmond, Washington 98052.

ICF Technology Incorporated

"Transportation Impacts of the Federal Waste Management System," October 1989, 9300 Lee Highway, Fairfax, Virginia 22031-1207.

"Historical MRS Siting and Transportation Studies: A Review and Analysis," June 1989, 9300 Lee Highway, Fairfax, Virginia 22031-1207.

"User Manual and Model Documentation: MARC (Model for Analysis of System Risk and Cost)," Version 1.0, July 1989, 9300 Lee Highway, Fairfax, Virginia 22031-1207.

Upon review of report prepared by Golder Associates, Inc., "Safety and Environmental Impacts for Alternative Spent Fuel Management Options," Letter Report from ICF Technology Incorporated, September 14, 1989, by Steve Baker, 601 Williams Boulevard, Fourth Floor, Richland, Washington 99352-3258.

Appendix F
Chronology of the Monitored Retrievable Storage Concept

Before 1970

At the end of the 1950s, commercial nuclear reactors began to produce electricity and, as a byproduct, spent fuel. Cumulative orders for nuclear reactors totaled about 74 million kilowatts just a decade later.[1]

The first International Scientific Conference on the Disposal of Radioactive Wastes was held in 1959. In the 1960s, nuclear waste experiments were being conducted in Kansas salt mines but there was little urgency in establishing a disposal program. Commercial spent fuel was to be reprocessed, with its residual uranium and plutonium recycled as fuel. However, there were problems with commercial reprocessing. The first reprocessing facility began operating in 1966 in West Valley, New York, but was shut down in 1972 for expansion; it never reopened due to increased seismic design requirements. A plant in Morris, Illinois, received a construction permit in 1967 but did not operate because of design and technical problems. A third plant, in Barnwell, South Carolina, received a construction permit and was essentially complete in 1977 when commercial reprocessing was indefinitely suspended.[2]

In May 1969, low-level, plutonium-contaminated debris from a fire at the Atomic Energy Commission's (AEC) weapons component facility in Rocky Flats, Colorado, was sent to the National Reactor Test Station in Idaho for storage. When Idaho's governor and its two U.S. senators protested, AEC Chairman Glenn Seaborg agreed to move the waste by 1980.

1970–1976

In 1970, the AEC formalized its policy for dealing with commercial high-level waste: such waste at reprocessing plants must be converted to solid form within five years of its generation; the solidified waste must be transferred to a Federal repository within 10 years after the irradiated fuel is reprocessed.[3]

In that same year (1970), the AEC tentatively selected a full-scale repository site in the salt deposits near Lyons, Kansas, pending confirmation tests. By 1972, however, the AEC had abandoned the Lyons site because of problems with the geologic formation's integrity. Many mining boreholes at the site and an unexplained disappearance of a large volume of water flushed into a nearby mine were two problems.[4]

With no deep geologic location in sight, the AEC shifted emphasis to aboveground, engineered structures—the first proposed monitored retrievable storage (MRS) facilities.[5] The AEC staff was instructed in February 1972 to begin designing surface storage facilities at a defense installation in Hanford, Washington, "for high-level commercial wastes and low-level wastes from both commercial and AEC activities."[6] In June 1972, the AEC revealed plans to develop a Retrievable Surface Storage Facility (RSSF), an array of mausolea or vaults where waste or spent fuel canisters would be stored.[7] The Joint Congressional Committee on Atomic Energy reported in 1972 that the radioactive waste management program "now includes the conceptual design of manmade surface facilities of an expected lifetime of several centuries, as well as research on burial in various geologic formations."[8] The decision to choose the surface storage option "was a response to the dilemma of irretrievability" and seemed a "practical answer to a difficult political and technical problem."[9]

Beginning in 1972, the AEC worked on three basic approaches to an RSSF: (1) stainless steel canisters in water basins to get rid of heat, and for shielding; (2) canisters in concrete basins, and cooled by circulating air; and (3) a canister within a 2-inch thick container with the doubly contained waste in a 3-foot thick concrete cask, and cooled by circulating air. An energy official said such storage would be satisfactory for decades, even centuries.[10] In 1973, AEC Chairman James Schlesinger said his agency's "near-term objective" was an engineered retrievable storage facility, although the "major effort" was a Federal repository "to be ready in the early 1980s."[11]

A year later, a new AEC chairman, Dr. Dixy Lee Ray, told the Congressional Joint Committee on Atomic Energy that a major waste management effort was "the engineering development of a facility to be ready in the early 1980s for the retrievable storage of solidified high-level waste from the commercial nuclear power industry. Our objective is to provide a surface facility based on proven technology where the waste can be safely stored until further treatment or disposal is available." She said evaluating geologic disposal was a separate objective.[12]

In September 1974, the AEC issued a draft environmental impact statement (EIS) on the civilian nuclear waste program, including the RSSF.[13] The RSSF was being designed to store all commercial high-level waste generated through the year 2000; it could store wastes for "at least 100 years."[14] Other RSSF features were retrievability of waste, ability to receive and store waste canisters, and safety in operations.

Two months later, the U.S. Environmental Protection Agency criticized AEC's draft EIS, saying the statement underemphasized the development of a repository.[15] Some western governors and other individuals also criticized the AEC's draft EIS.[16]

The Energy Reorganization Act of 1974 reorganized the Nation's energy program on January 17, 1975. The act abolished the Atomic Energy Commission and created two agencies—the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA).[17] ERDA, in its budget request for fiscal year 1976,[18] asked for funds for a Retrievable Surface Storage Facility at a site to be selected by July 1976, but withdrew that request and the environmental impact statement in April 1975.[19] Thus, the first approach to monitored retrievable storage did not reach the site selection stage mainly because of concern that it could become a permanent storage facility, preventing or delaying development of a geologic repository.

1977–1980

Nuclear waste storage entered a new phase when, on April 7, 1977, President Jimmy Carter deferred indefinitely all reprocessing of spent fuel from civilian power reactors. This step was taken to reduce the likelihood that the plutonium would be diverted from reprocessing to nuclear weapons construction.[20]

This presidential decision directly affected how spent fuel from nuclear power reactors was handled. Utilities had planned to send spent fuel to commercial reprocessing plants and often had provided only enough storage capacity to keep spent fuel at reactors for a limited time. With reprocessing indefinitely suspended, nuclear utilities had to reconsider the adequacy of at-reactor storage, and national policymakers had to reexamine the alternatives for storage and disposal of spent fuel from nuclear reactors.

With energy policy high on the public agenda, Congress created a Federal Department of Energy (DOE), which began operations on October 1, 1977.[21]

Seventeen days later, the Federal government proposed a modified version of the MRS approach—Federal away-from-reactor (AFR) storage of spent fuel. Under this proposal, the fuel owner would pay the Federal government for storage and disposal. DOE said that its acceptance and taking title to spent fuel from nuclear utilities would remove utility uncertainties about indefinite at-reactor storage of spent fuel.[22]

Because both interim and permanent spent fuel storage facilities were needed, the plan included a geologic repository that would permit retrieval of the spent fuel. One or more surface storage facilities would provide interim storage until the repository became available.[23]

DOE considered several alternatives over the next two years for this Federal away-from-reactor storage, including (a) building a 5,000-metric ton (MT) facility on a Federal site; (b) buying pools at three closed reprocessing plants; and (c) leasing storage space from the Tennessee Valley Authority.[24]

On March 15, 1978, President Carter set up an Interagency Review Group (IRG) on Nuclear Waste Management to recommend U.S. policy on nuclear waste disposal.[25] The IRG made its recommendations to the President in March 1979. While the report focused on permanent geologic disposal of nuclear waste, it recommended two interim measures: (1) AFR storage and (2) intermediate scale facilities (ISFs).

The IRG reported that "interim storage of spent fuel is required during the period of time before disposal facilities are available." While utilities should keep spent fuel at reactors until a repository is available, the Federal government "should provide storage capacity as needed for limited quantities of spent fuel" at the utilities' expense.[27] The report foresaw a maximum AFR capacity of 11,800 metric tons of heavy metal (MTHM) of spent fuel unless the first repository was delayed past 1989, in which case more AFR capacity would be needed.[28]

The Interagency Review Group called for "a stepwise approach to the development of an HLW [high-level waste] repository" while maintaining adequate storage capacity. The ISF would add technical, engineering, and operational data and provide learning experience about the licensing and organizational processes involved in developing a repository. While not "an essential component" leading to a full-scale repository, the IRG said the ISF should be built if there were "an appropriate opportunity" to do so "significantly prior to" opening a permanent repository.[29]

ISFs "can play a distinct and desirable role" in the transition "from R&D [research and development] to full-scale operational disposal facilities," the report stated. An ISF could store as many as 1,000 spent fuel assemblies or waste canisters with the possibility, but not the expectation, of removal. The report recommended immediately starting to site one or more ISFs in different emplacement media and geologic environments.[30]

The ISF, while depicted as a smaller scale geologic facility, had some characteristics of the MRS facility later proposed by DOE. It was a forerunner of the full-scale repository, providing earlier storage for spent fuel; a part of the step-wise approach to developing a repository; an advance exercise of the repository licensing process; and an experience in siting and building such a facility before siting and constructing a repository.

In February 1980, President Carter set forth a nuclear waste management policy, reflecting the IRG's recommendations. He emphasized the goal of permanent geologic disposal of nuclear waste; said nuclear spent fuel was the utilities' responsibility until the permanent Federal repository was built; and asked for authority to build or otherwise acquire away-from-reactor facilities for storing the spent fuel that utilities did not have room for at their reactor sites.[31]

Meanwhile, Congress began working on comprehensive nuclear waste management legislation. The Senate Energy and Natural Resources Committee bill (S. 2189), passed on July 30, 1980, authorized constructing monitored retrievable storage facilities to store wastes in aboveground vaults. The bill also included the administration's proposal to store utilities' excess spent fuel in AFR facilities; for this service, utilities would pay a one-time fee.[32]

The House, after months of hearings and negotiations among several committees, passed H.R. 8378 on December 3, 1980. The measure (1) set a timetable for developing a licensed, permanent repository, with NRC to decide on one site by 1992; (2) did not approve Federal away-from-reactor storage of spent fuel; and (3) did not authorize an MRS facility.[33]

However, the House-Senate conference committee could not agree on the bills. The 96th Congress, therefore, came close to enacting legislation concerning high-level nuclear waste but, at the last minute, could not decide on the provisions. MRS was a major bone of contention between the two houses of Congress.

1981–1982

In 1981, DOE reviewed the status of the MRS concept and analyzed its impact on the nuclear waste management system.[34] The study examined storage in dry wells, surface storage in concrete casks, and storage in air inside tunnels ("tunnel racks"). Potential MRS roles examined were: long-term storage (for 100 years) to allow relatively short-lived isotopes to decay before being disposed of in a geologic repository; dry away-from-reactor storage until fuel is reprocessed using a few large centralized storage facilities; and permanent storage, replacing the deep geologic repository. Economic evaluations for an MRS facility were based on spent fuel capacity of 48,000 MTHM. The DOE study suggested that the public would react adversely to deferring permanent disposal. The study also indicated that it would be difficult to get the public to accept a specific MRS or repository site.[35]

DOE also designed demonstration facilities capable of handling up to 1,000 canisters of spent fuel and ten high-level waste canisters—including two using open-field dry wells, one using a tunnel dry well, and one using a tunnel rack. DOE said it would take 9 to 11 years to complete a demonstration facility on a DOE site, including obtaining congressional authorization, meeting National Environmental Policy Act (NEPA) requirements, and obtaining an NRC license.[36] The designs could be expanded into full-scale facilities.

The same report said the Retrievable Surface Storage Facility was proposed in 1972 as the primary way to store high-level and transuranic vitrified waste resulting from reprocessing, allowing development of permanent disposal facilities on a longer term basis. Since the RSSF proposal was withdrawn in 1975, the report explained, ERDA and its successor agency, DOE, focused on developing permanent disposal.[37]

The 97th Congress began legislative activity on this issue in February 1981 but did not enact the Nuclear Waste Policy Act until December 1982. Senate committee chairmanships had shifted to Republicans. There was a new president, Ronald Reagan, whose administration changed many of the policies pursued by the Carter administration. The new administration:

- supported developing nuclear power;
- favored permanently disposing of high-level radioactive waste in a geologic repository;
- lifted the deferral of commercial reprocessing but offered no incentives to use reprocessing; no private reprocessing ventures were initiated;
- withdrew the Carter administration's offer to provide Federal away-from-reactor storage facilities, giving utilities primary responsibility for storing spent fuel until reprocessing or disposal facilities were developed;
- narrowed to three the number of repository sites to be examined before selecting one for licensing.[38]

In 1981, a number of bills were introduced in both houses of Congress but none reached the floor of either the House or Senate.

In 1982, nuclear waste legislation followed the 1980 pattern to a considerable extent: the Senate acted rather early in the year, the House passed a bill in December, and the House-Senate conferees worked into the week before Christmas to achieve an agreement. But in 1982, the conferees reached a compromise agreement on the Nuclear

Waste Policy Act of 1982, which Congress enacted on December 20 and the President signed on January 7, 1983.[39]

Title I, Subtitle C of the act said, "long-term storage of high-level radioactive waste or spent nuclear fuel" in MRS facilities "is an option." The legislation did not authorize an MRS facility, but did instruct DOE to submit to Congress by June 1, 1985, a proposal for constructing one or more MRS facilities. For the first MRS, the proposal was to include at least three alternative sites and at least five alternative combinations of sites and facility designs. Preparing the proposal required an environmental assessment, not an environmental impact statement. An MRS, if authorized, would have required an NRC license.

The act also directed DOE to enter into contracts with the generators and owners of spent fuel. The contracts provide that in exchange for a fee to be paid into a Nuclear Waste Fund, beginning not later than January 31, 1998, DOE would take title to the spent fuel and dispose of it in a geologic repository.[40] An MRS, if built, would be funded from the Nuclear Waste Fund.

The act further directed DOE to provide not more than 1,900 MT of storage for those utilities which could show that they could not reasonably provide adequate storage; this directive was intended to ensure the continued, orderly operation of the utilities' reactors.[41] The utilities were to pay for the storage,[42] and those needing it were to enter into contracts with DOE by January 1, 1990.[43] Existing Federal sites or the sites of any civilian nuclear power reactors were candidates for storage.

1983–1987

Following enactment of the Nuclear Waste Policy Act, the issue of managing nuclear waste shifted from the legislative to the executive branch. DOE presented its initial MRS plans in April 1984, in a draft mission plan which the Nuclear Waste Policy Act required. Under this plan, an MRS would provide backup storage in case the availability of a permanent repository was delayed significantly. Once a repository was available, utilities would ship spent fuel directly to it for packaging and disposal. When the at-reactor spent fuel backlog was reduced sufficiently, the MRS would ship its spent fuel to the repository for packaging and disposal.[44]

However, a DOE reassessment concluded in 1985 that an MRS facility should be an integral part of an "improved-performance" waste management system. Under this revised approach, the MRS facility would: receive spent fuel directly from most, possibly all, reactors; consolidate and package the fuel, including overpacking with disposal containers for permanent disposal in a repository; and store the fuel temporarily before shipment to the repository.[45]

DOE's 1985 mission plan for the civilian radioactive waste management program said the MRS facility in this "integral" waste management system "does not have the same role" as the earlier concept of an MRS facility.[46] Under the integral proposal, the MRS facility would be more than a storage operation; its main function would be preparing waste for emplacement in a repository.

In April 1985, DOE issued a preliminary analysis of the need for and feasibility of an MRS facility[47] and identified three sites in east and central Tennessee as the preferred and alternative locations for developing site-specific designs of MRS facilities. DOE's preferred location was at the Clinch River breeder reactor site, owned by the Tennessee Valley Authority (TVA) and adjacent to DOE's Oak Ridge reservation. Recommended alternatives were DOE's Oak Ridge reservation and TVA's cancelled Hartsville nuclear power plant site (northeast of Nashville).[48]

A proposal for the Tennessee MRS facility, including an environmental assessment and a program plan, was drafted in December 1985 to submit to Congress in early 1986. However, the proposal could not be submitted as planned because Tennessee filed suit charging DOE with failing to consult properly with the State before proposing the MRS sites. The U.S. District Court for the Middle District of Tennessee, on February 6, 1986, ruled in favor of the State, and, on February 7, issued an injunction prohibiting DOE from submitting the MRS proposal to Congress.[49]

The U.S. Court of Appeals for the Sixth Circuit reversed the District Court's decision on November 25, 1986.[50] Tennessee appealed to the U.S. Supreme Court which, on March 30, 1987, denied certiorari. The next day, DOE formally submitted its MRS proposal to Congress, recommending an MRS facility in Tennessee.[51]

1987–1989

DOE issued an amendment to its mission plan—in draft on January 28, 1987, and in final form in June—that:

- delayed the date on which nuclear waste could first be accepted at the repository from 1998 to 2003;
- formalized the decision, announced in May 1986, to postpone site-specific activities for the second repository;
- said the proposed integrated MRS would prepare spent fuel for emplacement in a repository, serve as a central receiving station, and act as a buffer for waste acceptance if the first repository were delayed; and
- proposed that the MRS be limited to 15,000 metric tons uranium (MTU), and not receive spent fuel un-

til the NRC had authorized constructing the repository, to meet concerns that the MRS facility could become a substitute for a permanent repository.[52]

Thus, the integral MRS was a vital part of DOE's overall strategy for nuclear waste management.

On March 31, 1987, Congress received DOE's proposal for an integral MRS facility to be built at the Clinch River site in Roane County, Tennessee, with interim storage limited to 15,000 MTU and with waste acceptance precluded until NRC authorized constructing the first repository. The proposal said the MRS would collect, process, and store wastes temporarily from eastern nuclear reactors, with spent fuel from western reactors normally being shipped directly to the repository.[53]

Meanwhile, congressional activity continued with many nuclear waste bills introduced in both houses in 1987. Nuclear waste ended up as one of many national issues in the Omnibus Budget Reconciliation Act. On December 21, the House and Senate approved the conference report on the budget reconciliation act, completing congressional action on the Nuclear Waste Policy Amendments Act of 1987 (NWPAA).[54] President Reagan signed the act on December 22, 1987.[55]

The 1987 amendments act reaffirmed the repository program as the primary focus of the Federal waste management effort. The act directed DOE to terminate all site-specific activities (other than reclamation) at all candidate repository sites other than Yucca Mountain.[56] The NWPAA "annulled and revoked" DOE's proposal to locate an MRS in Tennessee.[57] The amendments act created the Monitored Retrievable Storage Review Commission to prepare a report on whether a monitored retrievable storage facility is needed as part of a national nuclear waste management system that achieves the purposes of the Nuclear Waste Policy Act.[58] Congress specifically directed the Commission to compare using a monitored retrievable storage facility to using at-reactor storage before disposing of spent fuel in a repository.[59] Although the amendments authorized DOE to site, construct, and operate an MRS, the department was not authorized to survey or evaluate potentially suitable sites until the MRS Review Commission submitted its report.[60] Furthermore, the statute included certain conditions, to be incorporated in any MRS license the NRC issued, that closely link an MRS construction and operation to the repository schedule.[61]

The Commission's report was due June 1, 1989 but, in 1988, because of delays in appointing Commission members, Congress extended the due date to November 1, 1989.[62]

In May 1988, DOE initiated a series of system studies as part of updating its analysis of the MRS facility's role in the waste management system. DOE announced its revised policy position at a May 25, 1989 public briefing before the MRS Review Commission. DOE's preferred concept "is an integral MRS designed to allow development in stages."[63] In the first stage, the MRS facility would receive, inspect, and store spent fuel until shipment to the repository. Packaging spent fuel—part of the "integral MRS" concept advanced by DOE in 1985—would be optional and "could be added at a later date," according to DOE.[64]

The system studies "did not identify any significant benefit at present in consolidating or packaging spent fuel" at the MRS facility.[65] DOE concluded that a "basic MRS" (one that receives, stores, and stages waste for shipment to the repository) located in the Eastern United States "provides the greatest benefits to the waste-management system" for early and adequate acceptance of spent fuel, schedule confidence, and increased system flexibility. These benefits, DOE said, would be greater if the "linkages" in the 1987 amendments act were eliminated or modified, but DOE still favored an MRS even with the linkages.[66]

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Appendix G
Description of the Models

This appendix contains a description of the two principal analytic models, MARC and WACUM, used in this report, the acceptance schedules used in cost estimates, and the method used to locate an MRS for modeling purposes.

Section One: MARC Model

A. MARC Model Overview

MRS Review Commission's Analysis of System Risk and Cost (MARC) is a single-commodity, constrained-optimization model designed by ICF Technology Incorporated to aid the MRS Review Commission in comparing, in terms of risk and cost, alternative strategies for managing spent nuclear fuel. MARC is a modified version of a network optimization code originally developed by Battelle Memorial Institute called TRICAM (Transportation RIsk & Cost Analysis Model). In MARC, the scope has been expanded beyond TRICAM's focus on transportation to include the entire waste management system. The scope of the system modeled in MARC covers the generation of spent fuel at the Nation's commercial nuclear reactors, the temporary storage at these reactors (in the reactor pools and, where necessary due to pool storage capacity limits, in dry casks), storage and processing at MRS, transportation from the reactors and/or the MRS to the repository, and final packaging and burial of the spent fuel at the repository. MARC calculates the logistics solution (i.e., the schedules and quantities of spent fuel flows through user-defined storage and transportation systems from the reactors to final disposal at the repository), which minimizes the life-cycle system cost or risk or a linear combination of cost and risk. The computer routine within MARC which performs the actual optimization is NETFLO. NETFLO is documented in the literature.[1]

B. The Spent Fuel Management System as Modeled in MARC

The spent fuel management system is modeled in MARC using a primary network and a sub-network. The primary network comprises the three types of facilities in the system, i.e., the reactors at which the spent fuel is generated, up to three monitored retrievable storage facilities (commonly referred to as an MRS), and the final disposal facility (called the repository). The sub-networks model the various functions that can be performed at each such facility. This two-tiered network structure in MARC is described below.

1. Primary Network

Figure G.1 is a schematic representation of the primary network structure in MARC. It depicts, for a single year and for a single reactor, the various "paths" available to move the spent fuel from a reactor site to the repository, which is the permanent disposal site. Fuel discharged from reactors is placed in a storage pool for cooling. After it has been cooled sufficiently, it could be placed into dry casks stored at the reactor site. The transfer of spent fuel into the dry casks takes place in the pool. Under existing technology, the spent fuel is assumed to be transferred back into the pool for loading into a transport cask for shipment. Dry storage is part of the reactor sub-network. These components are included in illustrations of the primary network (Figures G.1 and G.2) to highlight the fact that dry storage is an integral part of MARC.

Inventories in the reactor pools, in dry storage at reactors, at the MRS, and at the repository provide the year-to-year linkage in MARC. The combined spatial-temporal network in MARC is depicted schematically in Figure G.2. (Note that Figures G.1 and G.2 show networks for a single reactor; in MARC, similar networks are generated for every reactor in the system.) Clearly, there are innumerable "paths" through space and time, including a stop at an MRS, along which spent fuel from a reactor can reach its final destination at the repository. The number of paths can exceed several million for the complete network containing all the reactors. MARC searches for the set of paths that would involve the least risk or cost, or variations thereof, for accomplishing the transfer of the spent nuclear fuel to the repository.

Arcs connecting the facilities represent the transportation alternatives available between them. For instance, two facilities between which both truck and rail service are available would be connected by two arcs, one for each mode. Transportation can occur between reactors (referred to as transshipment), from reactors to MRSs and repositories, and from the MRSs to the repository. The risks and costs of shipping a unit of waste along each arc are incorporated in MARC's objective function as the transportation coefficients.

2. Sub-networks

MARC models each facility through sub-networks, as shown in Figures G.3 through G.5. Nodes within such a facility sub-network are also connected by arcs, representing the functions that are to be performed at these facilities, such as storing, consolidating, packaging, receiving, and shipping. The unit risks and costs associated with these activities are incorporated into MARC's objective function as coefficients.

a. Reactor Sub-network

The sub-networks for reactors include three current year nodes (Figure G.3): a reactor pool node, the dry storage node, and the aggregate shipping node that includes both the pool and dry storage. In addition, there are two nodes that update the inventory of spent fuel from one year to the next. The flows of waste along the arcs connecting these nodes are described below.

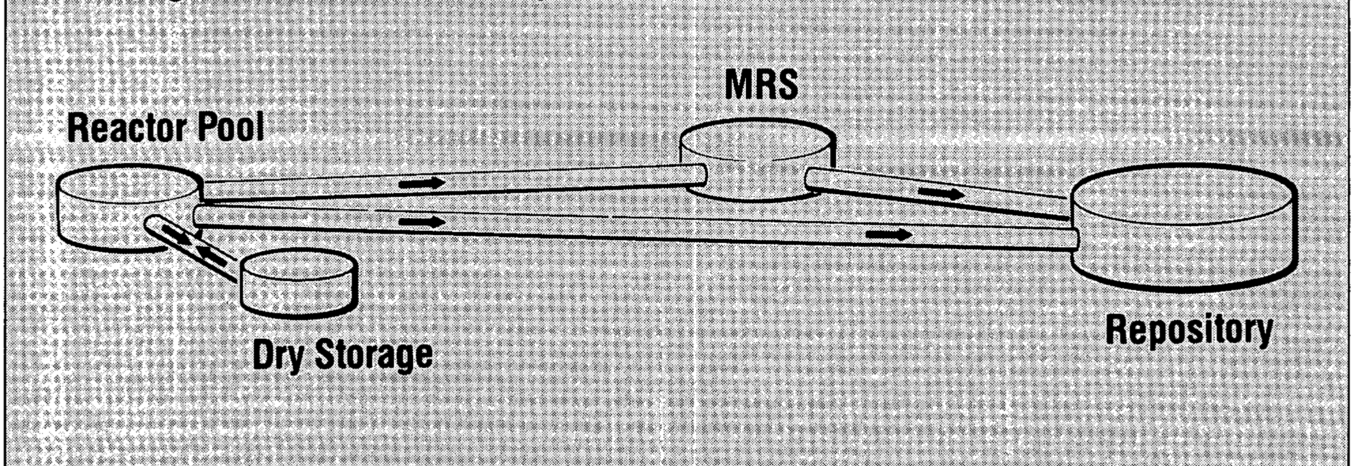
i. Reactor Pool Node

Waste can enter the current year reactor pool node from four sources. Discharges from the reactor during the year enter the reactor pool on arc 1. (See Figure G.3.) The previous year's inventory is carried over to the current year reactor pool node along arc 2. Transshipments from other reactor pools during the year enter on arc 3. Waste removed from dry storage for shipment enters on arc 8. Data for the spent fuel discharges (arc 1) are obtained from the discharge projections compiled at the Pacific Northwest Laboratory and updated each year.[2]

Consolidation of spent fuel, and associated re-packaging, can be modeled for specific reactors. When consolidation and packaging functions are activated for a reactor, the unit costs and risks for these functions are imposed on arc 1. The implicit assumption is that reactors consolidate 100 percent of the spent fuel in their pools, if consolidation at that reactor is selected. Consolidation occurs before any choices need to be made, such as shipping the fuel off-site or placing it in dry storage; thus, the consolidation or the packaging functions at reactors are inputs and are not part of the optimization performed in MARC.

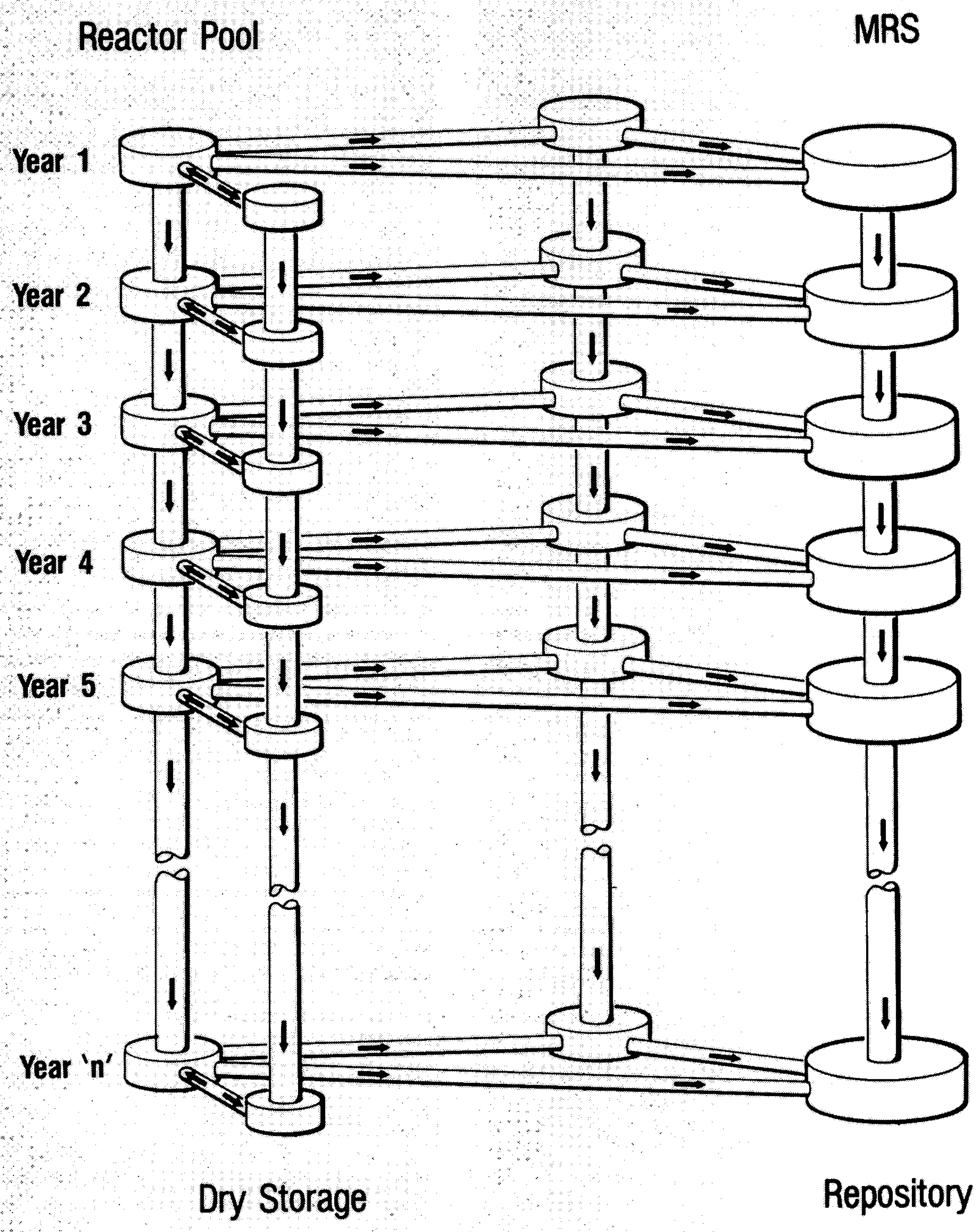
Outflows from the current year reactor pool node can occur on three arcs. Waste can be transferred to dry storage casks at the reactor site (arc 4), it can be removed from the pool for shipment (arc 5), or it can be kept in inventory, i.e., transferred to next year's reactor pool (arc 6). Arc 6 is an example of the year-to-year linkage in the model.

Figure G.1—Schematic Representation of the Spatial Network in MARC



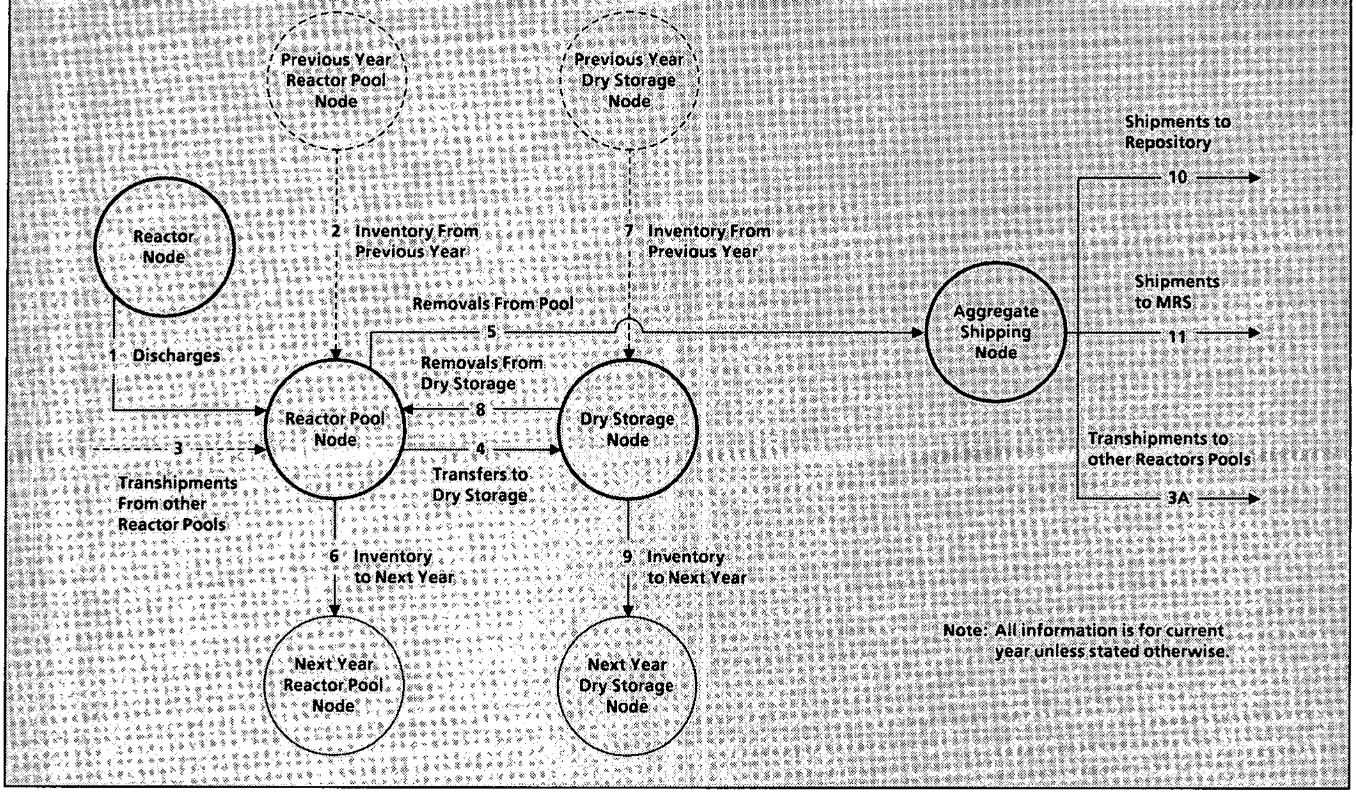
7 0 2 3 0 2 1 3 7

Figure G.2—Schematic Representation of the Space-time Network in MARC



7 0 2 3 0 2 1 3 8

Figure G.3—Reactor Sub-network



ii. Dry Storage Node

Waste is either placed in dry storage from the current-year reactor pool node (arc 4) or it is brought forward as inventory from the previous year dry storage node (arc 7). Outflows from the current year dry storage node include removals for shipment (arc 8) and transfers to the next year dry storage node (arc 9). Arc 9 is another year-to-year linkage in the model.

iii. Aggregate Shipping Node

The aggregate shipping node serves to constrain the total quantity of waste shipped from a reactor in a given year to no more than the annual shipping capacity of that reactor. Inflows into the aggregate shipping node are the removals from the reactor pool. (This may include spent fuel transferred to a transportation cask from dry storage, arc 5.) Shipments from this node can go to the repository (arc 10), the MRS (arc 11), or another reactor pool (arc 3A).

All reactors can ship by truck, but not all can ship by rail. Separate shipment arcs (not shown in the figure) are modeled for the modal option available at a reactor. For example, a reactor that can ship by truck and rail would be modeled with two shipment arcs each to the MRS and the repository. More than one cask type can be defined for a given mode, in which case additional arcs would be generated.

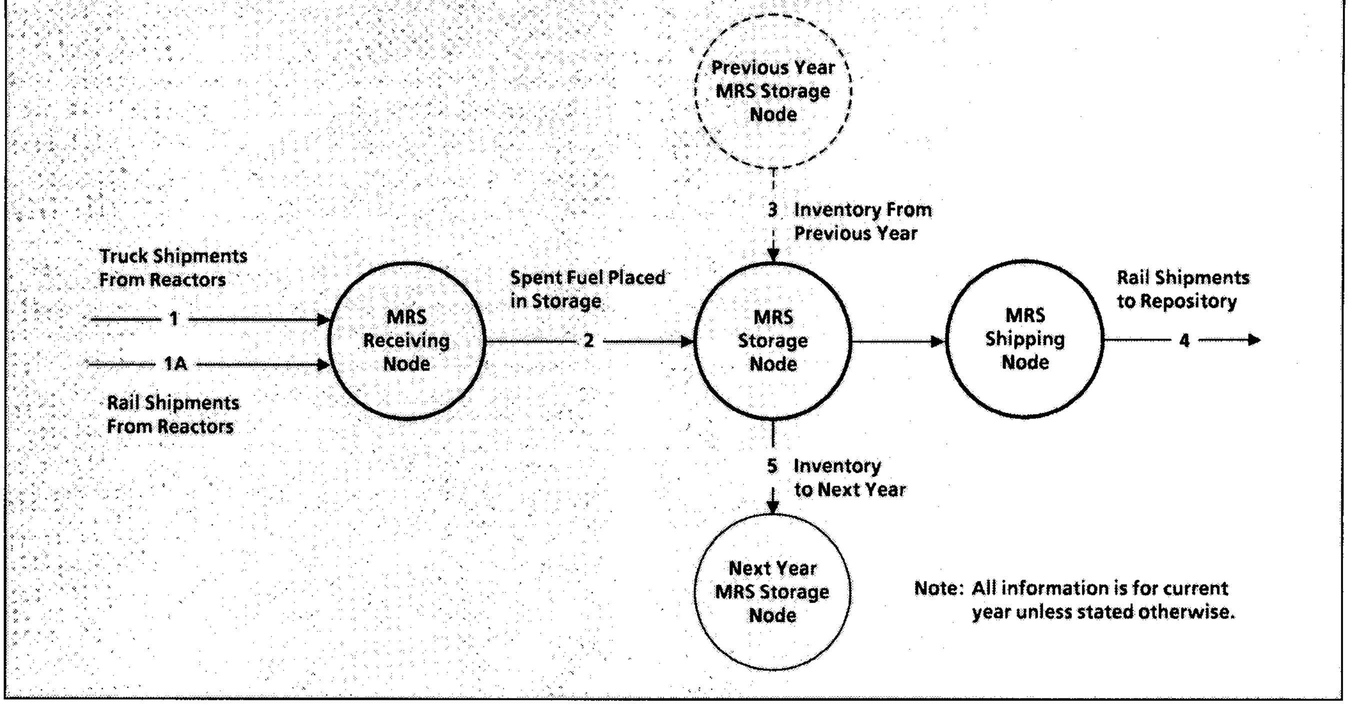
b. MRS Nodes

Figure G.4 is the sub-network for the MRS node. It comprises three current-year nodes: the receiving node, the storage node, and the shipping node. In addition, there is a node that updates the MRS inventory from one year to the next.

Shipments from the various reactors enter the MRS receiving node either on arc 1 or on arc 1A, depending on the shipment mode. The waste is gathered and placed in storage (arc 2) along with the previous year inventory (arc 3). Waste in the current-year storage node is either transferred to the shipping node for shipment to the repository (arc 4) or to the year storage node (arc 5). The MRS is assumed to ship to the repository by rail. However, if truck shipments are also to be considered, another shipment arc would be modeled. If consolidation and packaging at the MRS are selected, the unit costs for these activities are added to arc 2.

7 0 2 3 0 2 1 3 9

Figure G.4—MRS Sub-network



c. Repository Node

The formulation of the repository is fairly straightforward, as depicted in Figure G.5. There is a receiving node for shipments received in the current year from the reactors (arcs 1 and 1A) and from the MRS (arc 2). This waste is added to the inventory from the previous year (arc 4) and carried forward to the next year inventory (arc 5). The unit costs and risks of disposal are incorporated on arc 3. If consolidation and packaging are selected, the unit costs and risks for these functions are also included on arc 3. Note that there are no outflows from this node because the repository is the final disposal site for the waste.

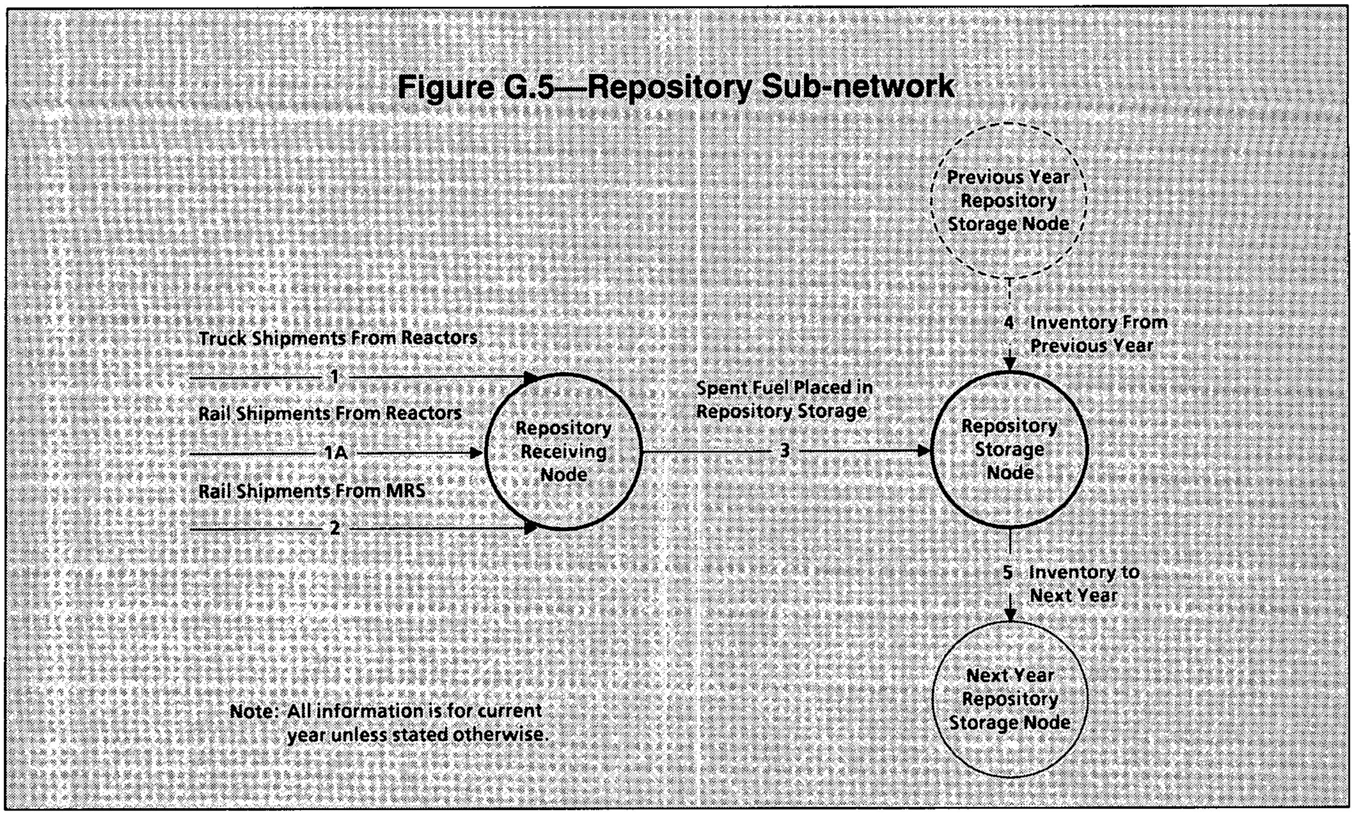
C. Constraints

MARC is a constrained optimization model. There are numerous types of constraints under which the optimization can be performed. All constraints in MARC are specified through MARC's interface module. (See the User Manual and Model Documentation[3] for a detailed description of all the constraints that are modeled in MARC and how they can be changed.) In general terms, the constraints in MARC include capacity and throughput limits. Capacity constraints relate to the maximum quantities that can be stored at a particular facility, whereas both the minimum and maximum levels can be specified for throughput rates. Examples of capacity constraints include the maximum quantity of spent fuel that can be stored in the various reactor pools and the maximum inventory that is allowed to be held at an MRS. An example of a throughput constraint is the maximum quantity of spent fuel that is allowed to be received at the MRS annually. This annual total can be disaggregated by mode, if the quantities received by truck and rail are required to be controlled separately. Minimum throughput rates can also be set, to force a desired quantity of fuel to be shipped to that facility. Furthermore, the user can specify whether inventory is allowed at the reactors and/or the MRSs at the end of the optimization. If ending inventory is disallowed at a given facility, then all fuel will be shipped out of that facility.

D. Objective Function

The objective function of the model minimizes the total lifetime risks or costs associated with the flows described in the previous section, without violating any of the constraints. To include both risks and costs in the objective function, a composite variable is computed for every arc in the model. This variable, referred to as the objective function coefficient (z_{ijt}), is a weighted average of the unit costs and risks associated with waste flows on these arcs. The weights are the relative values assigned to risk and

7 0 2 3 0 2 1 ? 0



cost, and are user-specified for each run. Specifically:

$$z_{ijt} = \alpha \bullet r_{ijt} + \beta \bullet c_{ijt} \quad (1)$$

where,

z_{ijt} = the objective function coefficient associated with moving 1 MTU (metric ton uranium) of waste along arc ij (i.e., from node i to node j) in year t,

r_{ijt} = the risk associated with moving 1 MTU of waste along arc ij in year t,

c_{ijt} = the cost associated with moving 1 MTU of waste along arc ij in year t,

α = the relative weight assigned to risk, and

β = the relative weight assigned to cost.

The objective function in the model is defined as:

$$\text{Minimize: } Z = \Sigma_i \Sigma_j \Sigma_t (z_{ijt} \bullet x_{ijt}) \quad (2)$$

where,

Z = the value of the objective function, and

x_{ijt} = the quantity of material flowing along arc ij in year t, measured in metric tons uranium (MTU).

For any specified constraint set, the model computes values for the material flows (x_{ijt}) which, taken together across all arcs and all years, minimize the value of the objective function (Equation 2). Note that the optimization occurs across the entire set of nodes and arcs over the life of the transportation program. This is not to say, however, that there will be activity on every arc in every solution; many x_{ijt}s will be zero.

E. Total Risk and Cost

The total risks and costs associated with the solution for any specified problem are calculated directly from the solution, as follows:

$$R = \Sigma_i \Sigma_j \Sigma_t (r_{ijt} \bullet X_{ijt}) \quad (3)$$
$$C = \Sigma_i \Sigma_j \Sigma_t (c_{ijt} \bullet X_{ijt}) \quad (4)$$

where,

R = the total risks associated with a particular solution, for all arcs and all years,

C = the total costs associated with a particular solution, for all arcs and all years, and

X_{ijt} = the computed values of x_{ijt} associated with a particular solution.

Section Two: Differences Between the Methodology/Data Used in this Study and in Previous Analyses

Analyses prepared by DOE and the University of Tennessee have relied on simulation models to evaluate transportation impacts for different waste management cases. As described above, MARC is an optimization program, and its methodology is fundamentally different from simulation. Simulation models require the analyst to prespecify how the system will operate through a series of rules and how it will respond to changes in scenario/strategy sets. Simulation models do not have any tradeoff logic and as such cannot determine the "best" solution given a set of constraints.

Constrained optimization, in contrast, seeks minimum cost or minimum risk solutions achievable for the specified scenario/strategy. MARC makes choices on the basis of total cost and risk that will be incurred over the life of the project and selects solutions that minimize these costs and risks.

An example of the difference between simulation and optimization helps to illustrate this point. In previous studies, DOE used a simulation program that relied on a spent fuel pick-up sequence based on the oldest fuel first rule. This rule specifies the order in which fuel is to be shipped from each reactor regardless of pool capacity constraints, thereby introducing inefficiencies in the way the system is operated. Calculations of cost under this situation will be higher than necessary. Optimization, on the other hand, does not require prespecification of the pick-up sequence. The choice of which fuel to ship is based instead on the most effective way to reduce cost and risk. MARC, for example, will evaluate pool capacity, the cost of alternative storage options on-site, the cost of shipping, and other factors in order to decide the sequence for shipping fuel.

Another example of the difference between these two methodologies occurs when an MRS is included in the waste management system. When DOE evaluated an eastern MRS, it specified that all of the reactors west of 100° longitude would ship directly to the western repository, and all reactors east of the line would first ship to the MRS. When these cases were run, reactors that were east of the dividing line but closer to the repository than the MRS ended up shipping all the way back east to the MRS, and then all the way west to the repository. MARC does not require the specification of such rules because shipping decisions are based on the lowest risk/cost strategy available.

In addition to the methodological differences, there are also data differences. First, MARC assesses cost and radiological risk for the entire spent fuel management system rather than just spent fuel transportation. Radiological risks (routine and accident-related) associated with waste management activities modeled in MARC are presented in an ICF Technology Incorporated letter to the MRS Review Commission, September 14, 1989. That letter contains estimates of worker and public management activities, as well as the rationale for dose estimates. Costs associated with waste management activities were developed by Golder Associates, Inc., and used in MARC.[4]

Second, some of the transportation data used in this study differ from data used in previous studies. The most important are the radiological risk values. Radiological risk data used in this study were taken from "Development of RADTRAN-Based Unit Risk Factors for Use in TRICAM," (Battelle 1989). These data were developed using the most updated version of RADTRAN (Modified RADTRAN III) rather than the earlier versions of RADTRAN that were used by DOE and the State of Tennessee.

DOE, in its most recent transportation system studies,[5] used radiological risk data provided by Argonne National Laboratory. A comparison of the Argonne and modified RADTRAN III risk estimates is currently underway at Argonne National Laboratory. It appears that Argonne's risk estimates are lower for truck shipments and higher for rail shipments than the data provided by modified RADTRAN III. However, the precise difference will not be known until Argonne completes its comparative evaluation.

The differences noted here between the methodology and data used in the present study and in the studies conducted prior to May 1989 are fully discussed in a review of these previous studies.[6]

Section Three: WACUM

A. Introduction

This section describes **WACUM**, the Nuclear **WA**ste **C**ost Data Base and Sim**U**lation **M**odel. WACUM was developed by Golder Associates, Inc., under contract number

T60355960 with the Monitored Retrievable Storage Review Commission. The purpose of the WACUM program is to provide cost estimates for the overall commercial interim spent nuclear fuel management system (ISFM) in the United States. WACUM does not address requirements for defense or commercial high-level waste.

WACUM, which runs on MS-DOS (IBM-compatible) personal computers, is written in the Turbo Pascal programming language, Version 5.0. The main modules in WACUM are:

- *WACUM simulator*: generation of a requirements file (see below) from a user-defined system strategy and operating scenario.
- *WACUM requirements editor*: interactive entry/editing of annual processing requirements, which specify the quantities and types of processes which will occur in the system.
- *WACUM costing module*: computation of the costs for an ISFM system to meet a set of requirements.
- *WACUM database editor*: interactive entry and editing of cost accounts, which contain cost estimates for individual components of the spent fuel handling system.

Figure G.6 shows the relationship between these modules.

The *WACUM simulator* takes as input a user-defined "strategy" defining the configuration of the spent fuel system, along with a "scenario" defining the dates at which different facilities (MRSs and repositories) will operate and their processing capacities. Input data are defined interactively by the user, and may be saved as a "strategy file." When a simulation is conducted, the strategy and scenarios are combined with data from historical and projected discharges of spent fuel from reactors. The product of the simulation is a "requirements file," which lists all of the processes which were required in the simulation, along with the location where the process occurred and the annual quantities required. A typical simulation takes about one minute to compute.

The *requirements file* is normally created by the WACUM simulator, but can be created using the requirements file editor if desired. The editor allows the user to look through the individual requirement records in the file and to modify, delete, or create new requirements. Individual requirement records can have their costs computed and displayed on the screen.

The *costing* option in WACUM uses the cost data base to compute the costs associated with the simulation. The cost data base, is discussed below in Part B.

The primary output of the costing option is two Lotus 1-2-3 Version 2.0(r) compatible data files, containing summary and detailed cost data. (See Figure G.6.) Costs for each account and for the totals are presented as an expected value and a tenth and ninetieth percentile value. WACUM uses the Monte Carlo method to compute the statistical distributions of the cost totals. A typical costing run takes about one minute to perform.

The *database edit* module allows the user to look through the cost account records and to modify, delete, or create new cost accounts. The cost data base is not normally modified by the user. The cost data base is described in "Interim Spent Fuel Management Cost Database Report," Dershowitz et al., June 1989.

All of the costs in WACUM are expressed in thousands of constant 1989 dollars. No allowance is made for inflation. However, the Lotus-compatible files produced by WACUM do contain formulas which enable the user to readily calculate the discounted costs in 1989 dollars.

B. Cost Data Base

The WACUM Encoded Cost Data Base contains subjective, probabilistic assessments for the unit costs of each of the modular cost accounts. This information was derived at a week-long probability encoding workshop held at Golder Associates, Inc., offices, Redmond, Washington, April, 1989. All of the unit costs in the encoded data base are expressed probabilistically, generally in terms of the minimum, most likely, and maximum possible values.

1. Design of Cost Accounts

The goals for the development of cost accounts were that they should be:

- comprehensive,
- mutually exclusive,
- modular, and
- capable of containing all costs for at-reactor, IFS, MRS, and repository storage, including:
  - facility costs (development and evaluation (D&E), design, and construction),
  - operation and maintenance,
  - transportation,
  - support systems,
  - institutional payments to affected states, and
  - licensing and permitting.

Several alternative cost account structures were considered, including systems based on the DOE cost account system utilized for the total system life-cycle cost analysis, systems based on physical components (such as hot cells), and systems based on functions (such as packaging). Due to the requirements of the WACUM code, the cost accounts were defined primarily in terms of function, although in some cases accounts were defined for major physical components required for a function.

2. Cost Accounts

Each cost account is defined by the function performed (e.g., consolidation, transportation, etc.), and the cost of providing that function is expressed in terms of fixed operating costs, variable operating costs, fixed (capital) costs, and development and evaluation costs. The total costs for the ISFM system, thus, consist of the requirements for the number of parameter units required of each function (e.g., MTU processed) times the parameter unit cost (e.g., $/MTU), summed over the various cost accounts.

The functional requirements (i.e., number of parameter units required for each function) are specified separately, either directly by the user in a "requirements file" or by the WACUM simulator. Cost accounts can contain components (such as a crane) which serve more than one function; in most cases, however, such items are contained in an infrastructure account.

Where possible, the cost accounts were defined in terms of unit costs (e.g., $/MTU, $/year, or $/item) in order to facilitate analysis of different strategies.

Fixed Costs represent the total cost of acquisition for the component. **D&E Costs,** which are charged only once no matter what quantity of the component is required, represent design, engineering, testing and licensing costs. **Fixed Operating Costs** are the annual cost of keeping the component in service, including amortization of replacement costs for components with short operating lives. **Variable Operating Costs** are directly related to the quantity of spent fuel processed in a given year.

Both fixed operating costs and variable operating costs are always paid in the year they are incurred. Fixed and D&E costs are paid according to defined schedules. Each schedule defines the **base year** for costing and the **start** and **end** years relative to the base year. As an example, the base year for fixed costs would be the startup date of the repository. Then, costs would accumulate starting six years before the repository start date and ending one year prior to the repository start date. The costs would be distributed uniformly over the six years.

3. WACUM Simulator

The simulator in WACUM tracks the movement of spent fuel on a year-by-year basis, from the originating pools to its eventual burial in a repository. The simulator is provided with the locations and capacities of all the pools, and with projected rates of discharge of spent fuel. It follows a series of rules, described below, to determine what happens each year from 1991 to 2050. The record of all of the operations that were required is then written to a requirements file, for subsequent costing.

The simulator follows a set of rules which define what actions are taken at each stage of the simulation. These rules represent a significant simplification of what might be expected in the real world. However, within the constraints imposed by operating on a PC, it is felt that the simulation is reasonable.

The simulator rules are as follows:

- For each year, the simulator first ships from reactors and MRS to fill available repository space. It then ships from reactors to fill available MRS space. Finally, it stores new fuel discharged at the reactors. When appropriate, reracking of reactor pools or at-reactor consolidation may be performed. Any excess fuel at the reactors is placed into dry storage. A full-core reserve is maintained in the reactor pools at all times prior to shutdown. An option is provided which allows direct shipment of unconsolidated fuel from reactors to a repository when the MRS is full. This is significantly more economical than routing all fuel through the MRS.
- The sequence in which spent fuel is selected for shipment from the reactors is as follows. The pick-up rule selected by the user (*oldest fuel first, oldest fuel first provided pool is reracked, or oldest fuel first provided pool is reracked and full*) is used to identify which reactors should ship in the current year to fill the combined repository and MRS available capacities. An option is provided to prioritize fuel from shutdown reactor pools. All reactors in the selected list which ship directly to a repository then do so. The balance of repository capacity, if any, is then filled by shipping from MRS to repositories. Finally, the available MRS capacity is then filled from the reactors, using the pick-up rule. Note that fuel is never shipped unless it is at least five years old.
- If there is insufficient qualified fuel according to the pick-up rule, the rule proceeds to the next lower level. Once all shipments have been processed, new discharges for the year are added to the reactor pools. If a pool is full (allowing a full-core reserve), dry storage is used. Requirements to rerack a pool or to consolidate fuel at a reactor pool are automatically triggered when the pool fills. (Consolidation only takes place if called for in the reactor strategy.)
- Fuel shipped out of a facility generates requirements for embarkation, to change storage modes (via the pool, for a reactor) to the shipping cask, and for transport.

- Fuel received at a facility generates requirements for debarkation, handling, and storage-mode changes as specified by the design of the facility. Consolidation, if required, occurs only after the fuel is changed to "bare" storage mode in a hot cell.
- Whenever fuel is changed to a new storage mode, the necessary number of casks are purchased (if not already available).
- The reactor data file contains the current capacity of each pool and the maximum capacity if it was reracked. WACUM will rerack a pool when it becomes full provided that the reracked capacity will be at least 20 percent greater than the initial capacity.
- At the reactors, consolidation of the fuel existing in the pool takes place if the consolidation option is selected and if the pool is reracked and full. Sufficient fuel is consolidated to create the required amount of spent fuel pool capacity.
- At each reactor, if there is any fuel left five years after the shutdown date, it is transferred to a dummy storage mode for post-shutdown storage, and a requirement for storage is generated. This generates a "maintenance" cost as long as there is any fuel at the reactor. The maintenance cost is variable, depending on the number of pools at the site and how many reactors are shut down.
- All reactor requirements are totalled in order to conserve memory space in the computer. As a result, all at-reactor cost accounts must have "unitized" costs, expressed per MTU.
- Transportation requirements are expressed in terms of the number of casks shipped, the transportation mode, and the origin and destination regions. The cost module converts these requirements to miles and days, to compute the number of vehicles and casks required, and the mileage costs.
- Dual-purpose casks received at a repository are not recycled.

A more complete description of the WACUM model and the data base it uses are available in "Interim Spent Fuel Management Cost Data Base: Report to the Monitored Retrievable Storage Review Commission"[7] and "WACUM: Nuclear Waste Cost Database and Simulation Model Users Guide Version 1.13: Report to the Monitored Retrievable Storage Review Commission."[8]

Section Four: Assumptions and Acceptance Schedules Used in WACUM Simulations

The assumptions and acceptance schedules used in the WACUM simulations generally follow those used by DOE in its system studies, but there were two significant exceptions. Rather than using the oldest fuel first pick-up rule, the WACUM base case simulations were made using a pick-up rule which assigned first priority to pools which were "full," i.e., any further storage would encroach on the reserve necessary to ensure the core of the reactor could be stored in the pool, and the pool had been fully reracked. Second priority was assigned to pools which were full but not fully reracked and third priority assigned according to the oldest fuel first principle. The oldest fuel first principle was also employed to assign priority within the group of pools which satisfied either the first or second criterion.

The other exception to the DOE analysis involved cases where a linked MRS had reached the point that it could no longer accept fuel because of an inventory limit. In such instances, reactors were allowed to ship directly to the repository. This assumption reduced the handling and processing costs at the MRS.

The acceptance schedule used for the repository and, where relevant, the MRS is shown below. For the cases in which the repository was assumed to begin operation in the year 2003 or the year 2013, ramp-up and acceptance rates identical to DOE's were used. However, a higher acceptance rate was used in the 2003 cases for that period of time after which the discharge of spent fuel from operating reactors and the withdrawal of spent fuel from at-reactor storage was not adequate to support the 3,000 MTU annual acceptance rate. For the cases in which the repository was delayed until the year 2023, higher acceptance rates were used because WACUM is limited to a 60-year modeling period.

Acceptance schedules used for the cases in which the repository began operation in the year 2003 were:

Repository: 2003 through 2005, 400 MTU/year; 2006, 900 MTU; 2007, 1,800 MTU; 2008 through 2033, 3,000 MTU/year; 2034 through 2045, 1,000 MTU/year.

MRS: 2000 and 2001, 1,200 MTU/year; 2002 and 2003, 2,000 MTU/year; 2004, 2,700 MTU/year; 2005 through 2028, 3,000 MTU/year; 2029 through 2045, 1,000 MTU/year.

Acceptance schedules for cases in which the repository began operation in the year 2013 were:

Repository: 2013 through 2015, 400 MTU/year; 2016, 900 MTU; 2017 1,800 MTU; 2018 through 2045, 3,000 MTU/year.

MRS: Unlinked MRS was the same as the schedule given above for the 2003 case. For the linked MRS the schedule was 2010 and 2011, 1,200 MTU/year; 2012 and 2013, 2,000 MTU/year; 2014, 2,700 MTU; 2015 through 2040, 3,000 MTU/year; 2040 through 2045, 1,000 MTU/year.

Acceptance schedules for cases in which the repository began operation in the year 2023 were:

Repository: 2023 through 2025, 400 MTU/year; 2026, 900 MTU; 2027, 1,800 MTU; 2028, 3,000 MTU; 2029 through 2050, 3,820 MTU/year.

MRS: Unlinked MRS was the same as the schedule given above for the 2003 cases except the acceptance period was extended from the year 2045 to the year 2050 at the rate of 1,000 MTU/year. For the linked MRS, the schedule was 2020 and 2021, 1,200 MTU/year; 2022 and 2023, 2,000 MTU/year; 2024, 2,700 MTU/year; 2025 through 2050, 3,120 MTU/year.

Section Five: MRS Location

For modeling purposes, the MRS was located in the Eastern United States. To perform the risk and transportation analyses in this study, a hypothetical location for an MRS was postulated. To do this, an averaging method was used in which the country was divided into six regions, and the geometric centroid of each was identified. The risks from the two eastern-most centroids were averaged to form a composite location. This methodology follows the methodology used in the DOE transportation system studies.[9] A sensitivity analysis was performed to determine the effects of MRS location on risk. In the cost analysis, the MRS was assumed to be located at the centroid of the Southeastern region.

Appendix G Notes

1. Kennington, J.L., and Helgason, R.V., *Algorithms for Network Programming*, New York: John Wiley & Sons (1980).

2. "Reactor-Specific Spent Fuel Discharge Projections: 1984 to 2020," PNL-5396, Pacific Northwest Laboratory, Richland, Washington (1985).

3. ICF Technology Incorporated, "MARC: User Manual and Model Documentation." (1989).

4. Dershowitz, W., Breeds, C., Roberds, W. and Miller, I. "Interim Spent Fuel Management Cost Data Base," 893-1032.120, June 20, 1989 **(Hereafter cited as Dershowitz et al.)**.

5. Office of Transportation Systems and Planning, Battelle Nuclear Systems Group, "MRS Systems Study, Task F: Transportation Impacts of a Monitored Retrievable Storage Facility," May 1989 **(Hereafter cited as Task F)**.

6. ICF Technology Incorporated, "Historical MRS Siting and Transportation Studies: A Review and Analysis," June 1989.

7. Dershowitz et al.

8. Miller, I. and Fuget, W., "WACUM: Nuclear Waste Cost Database and Simulation Model User's Guide Version 1.13: Report to the Monitored Retrievable Storage Review Commission," Golder Associates, Inc., Seattle: 1989.

9. Task F, pp. 16–20.

Figure G.6 - Sample Output
Summary Cost Table for WACUM Simulation of Linked MRS in 2010 and Repository in 2013 Case

1013r1 15kbMRS 87kr rrk rtbyp 10/14/1989 10 Account:
PV:
Edit discount rate in cell B3 0.04

	PRES VAL	EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
Grand Totals		TOTALS				CALENDAR					
TOTALS	$9,749,196	$27,960,012	$22,396,932	$34,390,608	$917,395	$73,024	$82,117	$77,998	$104,532	$100,446	$92,621
D & E	$2,971,423	$5,513,472	$5,190,079	$5,913,148	$820,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
Capital	$4,217,293	$10,649,944	$8,233,979	$13,544,434	$48,685	$20,055	$28,235	$24,145	$32,325	$30,689	$46,231
Fixed Operating	$1,037,817	$5,188,643	$3,465,241	$7,197,354	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$1,522,662	$6,607,955	$5,507,633	$7,735,672	$47,910	$12,169	$13,083	$13,054	$31,407	$28,958	$5,591
At-Reactor/Pool		TOTALS				CALENDAR					
		EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
TOTALS	$1,452,963	$3,681,024	$3,244,016	$4,195,865	$89,628	$25,257	$34,351	$30,232	$56,765	$52,680	$44,855
D & E	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital	$769,527	$1,370,325	$1,110,469	$1,681,136	$41,718	$13,088	$21,268	$17,178	$25,358	$23,722	$39,264
Fixed Operating	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$683,436	$2,310,699	$2,133,548	$2,514,729	$47,910	$12,169	$13,083	$13,054	$31,407	$28,958	$5,591
Development & Evaluat'n		TOTALS				CALENDAR					
		EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
TOTALS	$5,007,071	$9,698,476	$9,190,869	$10,306,007	$784,433	$47,767	$47,767	$47,767	$47,767	$47,767	$47,767
D & E	$2,931,359	$5,470,016	$5,170,843	$5,839,882	$777,467	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
Capital	$1,972,696	$3,763,922	$3,720,545	$3,813,757	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967	$6,967
Fixed Operating	$103,015	$464,538	$299,482	$652,368	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Transportation		TOTALS				CALENDAR					
		EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
TOTALS	$696,762	$3,299,413	$2,272,243	$4,425,650	$43,333	$0	$0	$0	$0	$0	$0
D & E	$40,064	$43,459	$19,236	$73,266	$43,333	$0	$0	$0	$0	$0	$0
Capital	$61,238	$176,043	$116,616	$243,340	$0	$0	$0	$0	$0	$0	$0
Fixed Operating	$282,400	$1,606,573	$1,054,662	$2,279,975	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$313,059	$1,473,338	$1,081,729	$1,829,070	$0	$0	$0	$0	$0	$0	$0
Yucca Mountain		TOTALS				CALENDAR					
		EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
TOTALS	$2,015,197	$9,216,199	$6,388,860	$12,507,642	$0	$0	$0	$0	$0	$0	$0
D & E	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital	$1,165,934	$4,769,001	$2,837,805	$7,101,636	$0	$0	$0	$0	$0	$0	$0
Fixed Operating	$328,652	$1,653,833	$1,283,109	$2,050,504	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$520,611	$2,793,365	$2,267,946	$3,355,502	$0	$0	$0	$0	$0	$0	$0
MRS		TOTALS				CALENDAR					
		EXP VAL	TENTH	NINETY	1991	1992	1993	1994	1995	1996	1997
TOTALS	$577,203	$2,064,901	$1,300,944	$2,955,445	$0	$0	$0	$0	$0	$0	$0
D & E	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Capital	$247,898	$570,650	$448,545	$704,565	$0	$0	$0	$0	$0	$0	$0
Fixed Operating	$323,749	$1,463,697	$827,989	$2,214,508	$0	$0	$0	$0	$0	$0	$0
Variable Operating	$5,556	$30,554	$24,411	$36,372	$0	$0	$0	$0	$0	$0	$0

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$479,335	$478,991	$502,508	$514,068	$520,673	$573,242	$591,103	$614,837	$633,011	$641,552	$782,327	$780,684	$798,044	$775,883
$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113
$267,506	$267,158	$290,674	$302,126	$308,670	$358,910	$357,274	$390,369	$416,388	$420,478	$561,148	$559,512	$495,590	$474,325
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$53,890	$54,015
$5,716	$5,721	$5,722	$5,830	$5,890	$8,220	$27,717	$18,356	$10,511	$14,961	$15,067	$15,060	$42,452	$41,430

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$58,068	$58,891	$58,892	$70,452	$77,056	$93,292	$111,153	$109,154	$106,217	$114,757	$127,133	$125,490	$90,994	$85,802
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$52,352	$53,170	$53,170	$64,622	$71,166	$85,072	$83,436	$90,798	$95,706	$99,796	$112,066	$110,430	$58,078	$53,170
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$5,716	$5,721	$5,722	$5,830	$5,890	$8,220	$27,717	$18,356	$10,511	$14,961	$15,067	$15,060	$32,916	$32,632

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$421,267	$420,100	$433,383	$433,383	$433,383	$433,383	$433,383	$433,383	$433,383	$433,383	$433,383	$433,383	$432,933	$432,933
$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113	$206,113
$215,154	$213,988	$227,271	$227,271	$227,271	$227,271	$227,271	$227,271	$227,271	$227,271	$227,271	$227,271	$213,988	$213,988
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$12,833	$12,833
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$22,657	$10,889
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$13,080	$1,923
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,127	$1,252
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$8,451	$7,714

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$0	$0	$0	$0	$0	$36,333	$36,333	$36,333	$36,333	$36,333	$164,733	$185,844	$185,844	$185,844
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$36,333	$36,333	$36,333	$36,333	$36,333	$164,733	$185,844	$185,844	$185,844
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
$0	$0	$10,233	$10,233	$10,233	$10,233	$10,233	$35,967	$57,078	$57,078	$57,078	$35,967	$65,615	$60,415
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$10,233	$10,233	$10,233	$10,233	$10,233	$35,967	$57,078	$57,078	$57,078	$35,967	$24,600	$19,400
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$39,930	$39,930
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,085	$1,085

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2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$730,995	$785,660	$321,175	$333,905	$375,192	$384,660	$516,931	$544,261	$541,154	$542,981	$557,001	$554,752	$556,418	$552,128
$206,113	$206,113	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
$436,505	$391,950	$84,922	$89,373	$99,230	$87,243	$134,447	$137,419	$133,676	$134,094	$142,023	$131,967	$135,143	$136,155
$55,093	$132,973	$133,273	$133,650	$134,025	$134,152	$146,558	$146,558	$146,558	$146,558	$146,810	$146,810	$146,810	$146,935
$33,284	$54,625	$62,180	$70,083	$101,137	$122,465	$195,125	$219,483	$220,120	$221,529	$227,367	$235,175	$233,665	$228,237

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$39,269	$35,820	$40,326	$43,530	$39,591	$42,752	$51,653	$71,665	$69,991	$75,955	$88,770	$84,715	$88,919	$89,358
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$18,814	$15,542	$15,542	$13,906	$4,090	$4,090	$2,454	$5,726	$1,636	$2,454	$8,180	$0	$4,090	$3,272
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$20,455	$20,278	$24,784	$29,624	$35,501	$38,662	$49,199	$65,939	$68,355	$73,501	$80,590	$84,715	$84,829	$86,086

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$432,933	$432,933	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433
$206,113	$206,113	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
$213,988	$213,988	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800
$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$19,270	$174,189	$66,586	$70,082	$80,013	$69,116	$91,303	$98,608	$96,807	$93,112	$94,324	$95,773	$94,173	$89,532
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$6,370	$113,813	$3,573	$4,147	$4,467	$1,900	$300	$0	$0	$0	$2,223	$0	$0	$1,923
$1,880	$40,147	$40,447	$40,823	$41,198	$41,325	$41,452	$41,452	$41,452	$41,452	$41,703	$41,703	$41,703	$41,828
$11,020	$20,229	$22,566	$25,112	$34,348	$25,891	$49,551	$57,156	$55,356	$51,660	$50,397	$54,070	$52,470	$45,780

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$164,733	$68,130	$68,209	$68,968	$105,752	$172,081	$273,940	$273,939	$274,093	$274,092	$273,869	$274,016	$273,503	$273,211
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$164,733	$16,207	$16,207	$16,720	$37,473	$74,653	$125,693	$125,693	$125,840	$125,840	$125,620	$125,767	$125,253	$124,960
$0	$39,613	$39,613	$39,613	$39,613	$39,613	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893
$0	$12,310	$12,389	$12,635	$28,665	$57,814	$96,354	$96,352	$96,360	$96,359	$96,356	$96,356	$96,357	$96,358

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
$74,788	$74,588	$86,621	$91,892	$90,403	$41,278	$40,601	$40,617	$40,830	$40,389	$40,604	$40,815	$40,389	$40,594
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$32,600	$32,400	$43,800	$48,800	$47,400	$800	$200	$200	$400	$0	$200	$400	$0	$200
$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380
$1,808	$1,808	$2,441	$2,712	$2,623	$98	$21	$37	$50	$9	$24	$35	$9	$14

2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$565,317	$564,961	$570,370	$579,613	$585,449	$585,644	$587,286	$570,407	$553,016	$541,187	$526,283	$521,076	$497,560	$481,978
$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
$135,241	$133,383	$131,987	$131,787	$131,620	$131,820	$131,767	$131,493	$131,547	$132,060	$132,060	$133,313	$131,727	$133,870
$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,010	$147,135
$242,266	$243,768	$250,573	$260,016	$266,019	$266,014	$267,709	$251,103	$233,660	$221,317	$206,413	$199,952	$178,023	$160,173
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$90,577	$95,916	$102,504	$108,514	$114,893	$113,407	$116,942	$96,276	$84,230	$72,490	$66,779	$60,208	$40,521	$23,711
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$2,454	$1,636	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$88,123	$94,280	$102,504	$108,514	$114,893	$113,407	$116,942	$96,276	$84,230	$72,490	$66,779	$60,208	$40,521	$23,711
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433	$59,433
$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800	$40,800
$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800	$5,800
$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$12,833
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$100,525	$95,000	$93,595	$97,051	$96,653	$98,113	$96,290	$100,368	$94,960	$94,347	$85,153	$85,111	$82,964	$83,997
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$893	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,923
$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$41,903	$42,028
$57,728	$53,096	$51,691	$55,147	$54,749	$56,209	$54,387	$58,464	$53,057	$52,444	$43,250	$43,208	$41,061	$40,046
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$273,943	$273,798	$274,227	$274,234	$273,861	$273,863	$274,017	$273,945	$273,795	$274,309	$274,311	$274,163	$273,577	$273,787
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$125,693	$125,547	$125,987	$125,987	$125,620	$125,620	$125,767	$125,693	$125,547	$126,060	$126,060	$125,913	$125,327	$125,547
$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$51,893
$96,356	$96,358	$96,347	$96,354	$96,348	$96,350	$96,357	$96,359	$96,355	$96,356	$96,357	$96,356	$96,357	$96,347
2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
$40,839	$40,814	$40,611	$40,381	$40,609	$40,828	$40,603	$40,384	$40,598	$40,608	$40,607	$42,161	$41,064	$41,050
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$400	$400	$200	$0	$200	$400	$200	$0	$200	$200	$200	$1,600	$600	$600
$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$40,380
$59	$34	$31	$1	$29	$48	$23	$4	$18	$28	$27	$181	$84	$70

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$467,578	$416,524	$406,971	$405,420	$404,342	$324,957	$57,144	$57,144	$57,144	$57,144	$103,811
$40,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$46,667
$139,020	$137,027	$125,033	$125,693	$124,960	$93,069	$13,722	$13,722	$13,722	$13,722	$13,722
$147,642	$148,528	$148,528	$148,528	$148,528	$148,528	$43,422	$43,422	$43,422	$43,422	$43,422
$140,117	$130,969	$133,409	$131,198	$130,854	$83,360	$0	$0	$0	$0	$0

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$3,429	$96	$2,295	$358	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$3,429	$96	$2,295	$358	$0	$0	$0	$0	$0	$0	$0

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$59,433	$12,833	$12,833	$12,833	$12,833	$12,833	$0	$0	$0	$0	$46,667
$40,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$46,667
$5,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$12,833	$12,833	$12,833	$12,833	$12,833	$12,833	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$89,147	$86,468	$75,009	$74,806	$74,722	$63,526	$43,422	$43,422	$43,422	$43,422	$43,422
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$7,600	$11,700	$0	$0	$0	$0	$0	$0	$0	$0	$0
$42,535	$43,422	$43,422	$43,422	$43,422	$43,422	$43,422	$43,422	$43,422	$43,422	$43,422
$39,012	$31,347	$31,587	$31,385	$31,300	$20,104	$0	$0	$0	$0	$0

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$273,863	$273,575	$273,281	$273,945	$273,207	$203,130	$10,667	$10,667	$10,667	$10,667	$10,667
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$125,620	$125,327	$125,033	$125,693	$124,960	$90,013	$10,667	$10,667	$10,667	$10,667	$10,667
$51,893	$51,893	$51,893	$51,893	$51,893	$51,893	$0	$0	$0	$0	$0
$96,350	$96,355	$96,354	$96,359	$96,354	$61,223	$0	$0	$0	$0	$0

2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
$41,705	$43,552	$43,553	$43,477	$43,580	$45,469	$3,056	$3,056	$3,056	$3,056	$3,056
$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
$0	$0	$0	$0	$0	$3,056	$3,056	$3,056	$3,056	$3,056	$3,056
$40,380	$40,380	$40,380	$40,380	$40,380	$40,380	$0	$0	$0	$0	$0
$1,325	$3,172	$3,173	$3,097	$3,200	$2,033	$0	$0	$0	$0	$0

Appendix H
Sensitivity Analyses

The base cases evaluated in this report are discussed in Chapter Three. Variations on these base case strategies were evaluated in Chapters Four and Five of the report to determine the sensitivity of system risks and costs to modifications in the base case strategies. This appendix describes the variations evaluated.

Section One: Health, Safety, and Environmental Impacts

Sensitivity analyses were performed in Chapter Four for each of the base cases strategies. A 2013 repository start date was selected for the sensitivity analyses because it was considered at that time a more likely repository start date than 2003 or 2023. However, the purpose of the sensitivity analyses was to determine the sensitivity of risk estimates to changes in a single key parameter or groups of parameters, and either of the other repository start dates would have given similar results.

A. Variations on the No-MRS Strategy

The variations on the No-MRS strategy are summarized in Table H.1 and discussed below.

TABLE H.1—VARIATIONS ON THE NO-MRS STRATEGY

- Intrautility transshipment allowed
- 50% at-reactor consolidation
- 100% rail transportation
- 100% rail transportation (avoid population centers > 500,000 people)
- Dual-purpose casks
- Dual-purpose casks + 100% rail transportation

1. Intrautility Transshipment Allowed

Transshipment of spent fuel between reactors of the same type (e.g., PWRs) owned by the same utility is allowed as a means for providing additional spent fuel storage capacity, if needed at a reactor to maintain full-core reserve.

2. Fifty Percent At-reactor Consolidation

This variation assumes 50 percent of all spent fuel is consolidated at reactor sites. Only reactors that could obtain life-of-plant pool storage would be expected to use rod consolidation since it is unlikely utilities would adopt a strategy that would require two different techniques (rod consolidation and dry storage) for increasing spent fuel storage capacity. If these reactors consolidated all of their spent fuel, about 50 percent of all spent fuel would be consolidated at reactors.

3. One Hundred Percent Rail Transportation

The base case assumes 54 percent of reactors can ship by rail, the same assumption used by DOE in its system studies. This case assumes all reactors ship by rail (regardless of whether or not they presently have the capability to do so). The objective is to ascertain the maximum benefit that could be obtained by switching to rail shipment. This variation would bound the State of Tennessee's estimates.

4. One Hundred Percent Rail Transportation (Avoid Population Centers >500,000 People)

In this case, all shipments are routed so that there are no spent fuel shipments through population centers greater than 500,000 people. The purpose is to ascertain whether such routing will substantially affect public risk.

5. Dual-purpose Casks

A dual-purpose cask is used both to store and transport spent fuel. It can be reused after spent fuel is removed from the cask following transportation from the reactor to the repository or an MRS. The reuse may be for either storage or transport. The appeal of this concept lies in the potential to minimize handling of spent fuel. For this case, the analysis assumes dual-purpose casks are used to store and ship spent fuel. For this case and the next, the analysis assumes: (1) the dual-purpose cask will be licensed and available when needed; (2) even after prolonged storage, the dual-purpose cask would not have to be opened to be recertified for transport.

6. Dual-purpose Casks Plus 100 Percent Rail Transportation

In this case, the analysis assumes dual-purpose casks are used to store and ship spent fuel, and all spent fuel is shipped by rail.

B. Variations on the MRS Strategies

The variations on the MRS strategies are summarized in Table H.2 and discussed below.

TABLE H.2—VARIATIONS ON THE MRS STRATEGIES

- Intrautility transshipment allowed
- Unlinked MRS inventory limits
- Alternative MRS schedule linkage
- Unlinked MRS located in central U. S.
- Consolidation at the unlinked MRS

1. Intrautility Transshipment Allowed

See explanation under variations on No-MRS strategy.

2. Unlinked MRS Inventory Limits

In the unlinked MRS base case, there were no inventory limits. In the sensitivity analysis, inventory limits of 5,000, 15,000, and 30,000 MTU of spent fuel were used to determine the effects of varying inventory limits.

3. Alternative MRS Schedule Linkage

In the linked MRS (NWPAA) base case, the MRS schedule was linked to the repository schedule in accordance with the NWPAA. The practical effect of this linkage is that the MRS could begin operation no earlier than about three years before the repository. In this variation, it is assumed that the MRS can begin operation five years before the repository. This allows a determination of the effect of a relaxation in the schedule linkage. The capacity limits still hold.

4. Unlinked MRS Located in Central U.S.

In the linked and unlinked base cases, the MRS is assumed to be located in the Eastern United States. This case assumes an MRS facility at a hypothetical location in the Central United States. The effects of the transportation to and from hypothetical MRS facilities located in the northern and southern centroids in the central third of the country were calculated and then averaged.

Section Two: Spent Fuel Transportation Safety

All cases in Chapter Five were analyzed with the repository beginning operations in 2013.

For the No-MRS strategy, the variations are the same as those listed in Table H.1 except that dual-purpose casks were analyzed with the use of 100 percent rail transport only.

For the linked and unlinked MRS strategy, the variations are as listed in Table H.2 except that inventory limits and schedule linkages were restricted to fewer cases than in Chapter Four, and there was no consolidation at the MRS.

Appendix I

The Commission's Recommendations: Cost, Capacity, and Financing

Section One: Costs

The Commission's recommendations to create the Federal Emergency Storage (FES) and User-Funded Interim Storage (UFIS) facilities do not rest on the expectation that they would reduce the cost of the spent fuel management and disposal system. The FES is intended to provide resilience to the system by insuring that spent fuel can be removed expeditiously from a reactor pool in an emergency and to provide storage for reactors that would have to shut down because they were unable to build at-reactor dry storage facilities. The UFIS will provide an alternative to on-site dry storage for utilities that choose to use it, at their own expense. The UFIS may reduce the share of the total cost that comes from the Nuclear Waste Fund, but it is unlikely to reduce overall system cost.

The annual Federal Interim Storage Fee Study[1] estimates the cost of storage facilities for a number of alternative types, sizes, and locations. In the 1988 report, the capital costs for a 1,900 MTU facility ranged from a low of $140 million for a facility located at a site where transfer facilities and hot cell facilities were already in existence and made use of a field drywell storage system to a high of $220 million for a facility located at a site without transfer or hot cell facilities using dry cask storage.

The Commission also asked Golder Associates Inc., who developed the cost data base and simulation model described in Chapter Six, to provide some preliminary cost estimates. These estimates were based on the encoded cost data base described in Chapter Six, which explicitly incorporates uncertainty about the future escalation of such costs. Thus, they are higher than today's engineering estimates of what it would cost to build and operate such facilities. As emphasized in their report, these estimates were "very preliminary, order of magnitude only."[2] Golder estimated that the capital cost of a 2,000 MTU capacity facility built at a site with existing hot cell and transfer facilities using dry casks for storage would be $330 million. The capital cost of the same facility built at a site without these facilities was estimated to be $370 million.

For a 5,000 MTU facility using dry cask storage, Golder estimated the capital cost to be $530 million if built at a site with transfer facilities and hot cells and $570 million if built at a site without such facilities.

Section Two: Capacity

The recommended capacities of the FES and UFIS are not intended to provide for all storage needs over the life cycle of the national spent fuel management system. The Commission's objective is to provide a prudent degree of resiliency and redundancy in the system over the next 10 to 15 years. The recommendations assume that, as outlined in Recommendation No. 3 in Chapter Nine, the Congress will reconsider the subject of interim storage by the year 2000; the recommendations also reflect the concerns that have been expressed about such facilities becoming a de facto repository.

The FES facility's principal purpose is to provide a place for spent fuel should there be an emergency at a reactor, which would make it desirable to remove all of the fuel stored in the pool. As indicated in Chapter Nine, about 1,000 MTU of capacity would be required to empty a large, full pool at an operating reactor and would always be reserved for that purpose. The remaining 1,000 MTU of capacity would be available for use by utilities that would have to shut down before the end of their designed operating life because they were unable to provide on-site dry storage if the UFIS were not available.

Until the Facility Interface Capability Assessment (FICA) survey being conducted by DOE on reactor capabilities is completed, it will not be possible to ascertain how many, if any, reactors will be unable to accommodate at their sites all of the spent fuel they will discharge. However, if neither a repository nor an MRS were available, in 20 years about 13,900 MTU of dry storage capacity would be needed at reactor sites. Assuming that utilities plan at least five years ahead, provision has already been made for about 1,300 MTU of dry storage. Thus, even if as many as 10 percent of the reactors were to find it impossible to store additional discharges of spent fuel on-site, the provision of 1,000 MTU of capacity for this purpose seems reasonable and conservative over the 10- to 15-year planning horizon the Commission has used.

Reserving 1,000 MTU for emergency purposes also appears to be a reasonable and conservative assumption. Emergencies at nuclear power plants that would require the reactor to shut down or a pool to be emptied are rare events. The frequency of rare events is difficult to predict. However, some calculations that provide rough estimates are available. The *Reactor Safety Study*, commonly referred to as WASH-1400 or the Rasmussen Report, which was published by the NRC in 1975, estimated that the probability of a serious accident involving a core meltdown, in the current generation of reactors, was 1/20,000 per reactor year.[3] Assuming 100 reactors will be operating over the next 20 years, there would be 2,000 reactor years. Using the WASH-1400 probability estimate of a core meltdown as the probability of a serious accident would mean that the probability of a serious accident occurring during that time period would be equal to 2,000 x 1/20,000 or 10 percent.

The risk estimates in WASH-1400 have been criticized from a number of perspectives.[4] The Lewis Report[5] concluded that the estimates may be off by one order of magnitude in either direction, which would mean that over the time period in question, the probability of a serious accident would range from a low of 1 percent to a high of 100 percent. In any event, the Commission believes the probability that a serious accident may occur is not negligible, thus, it would be prudent to maintain a capability to deal expeditiously with the possible need to remove the spent fuel from the pool. A reasonable estimate of the capacity required to accomplish this appears to be 1,000 MTU.

Section Three: Financing

In its submission to the Congress of the MRS Program Plan, DOE presented a funding plan calling for the MRS to be financed through the Nuclear Waste Fund. It said it did not consider user funding for an MRS because:

> [A]n approach that imposes a surcharge on only the generators and owners of spent fuel that passes through the MRS facility would be inconsistent with the integral nature of the MRS facility. The decision of which fuel will pass through the MRS facility rests on overall system considerations and not on the preferences of individual utilities. Hence, this approach is not considered further.[6]

As DOE's proposed MRS has evolved from a comprehensive packaging, consolidation, storage, and logistical facility into a simpler "basic" facility providing only storage and logistics, this logic has become less persuasive, particularly if the facility is constrained by an inventory limit.

As explained in Chapter Seven, the smaller the MRS, the more limited its services, and the fewer the number of utilities that make use of it, the weaker the case for general, industry-wide financing on both equity and economic efficiency grounds. Thus, the Commission recommends that its UFIS, a 5,000 MTU, optional, off-line, centralized interim storage facility, be user funded.

There are two basic ways to design user-fee systems: a cost approach and an auction approach.

The *cost approach* is illustrated in considerable detail in the annual Federal Interim Storage Fee studies, which have been prepared by E.R. Johnson Associates, Inc., for the Department of Energy since 1983.[7]

The cost approach is normally utilized when the demand for the facility is expected to be smaller than its potential capacity. In the case of an FIS, E.R. Johnson Associates has identified 13 utility sites as prospective FIS users. By 1995, they estimate, these sites will have a combined demand of only 1,286 MTU compared to an authorized FIS capacity of 1,900 MTU. Since none of the sites has applied to use the FIS and the report assumes an MRS will open in 1998 followed by a repository in 2003, the expectation that the demand for an FIS would be less than its authorized 1,900 MTU limit appears quite conservative. If the demand for the facility were expected to exceed its capacity, a lottery or some sort of "needs" criteria for making an administrative determination would have to be used to decide who would get the available capacity and who would not.

The *auction system* is the second approach to designing a user-fee system. It is based on price rather than cost. It is best suited to a situation in which the demand for the facility is uncertain or is expected to be greater than the capacity of the facility. If there is more storage needed than the facility is able or permitted to provide, letting potential users bid for it helps insure that the use will go to those who "need" or value it most (in the sense that they are willing to pay the highest price to acquire it).

Similarly, if it is not clear that there are enough interested users to justify building a facility, holding an auction provides a mechanism for ascertaining how much storage is desired and whether potential users are willing to pay enough to enable the government to provide the service. If the proceeds from the auction were not sufficient to cover the cost of building the facility, it simply would not be built. Subsequent auctions could be held, however, to ascertain if conditions or expectations had changed sufficiently to warrant building the facility.

The design criterion underlying the *cost approach* is to insure that the fees cover all capital and operating costs of the facility. This is done with a two-fee system. As outlined in the annual FIS report prepared by E.R. Johnson Associates, an "initial" fee, paid when the contract is signed, covers all construction and licensing expenses expected to be incurred before the facility opens. Then a "final" fee is determined which covers: (1) transportation costs to the FIS, (2) estimated operating and decommissioning costs, and (3) an adjustment for any over or under estimates that may have been made in establishing the "initial" fee. The final fee is paid when the fuel is delivered to the FIS. Since the report assumes a repository will be available in 2003 and the fuel from the FIS will have to be transferred within three years as specified by the NWPA, there is little (assumed) uncertainty about how long the spent fuel will be stored at the facility. In the case of a UFIS, there might be considerably more uncertainty and, thus, it would probably be prudent to make the operating expenses an annual fee, payable as long as the fuel remained at the facility, rather than part of a "final" fee.

Under the *auction approach*, an auction would be held at which prospective users would bid for the available storage capacity with the highest bidders winning the right to store spent fuel at the facility. In order to assure that the fees collected cover all costs of the facility, a variation of the two-fee system described in the cost approach above could be used. The initial fee would be set on the basis of bids received at auction and paid when construction was initiated. The final fee and annual operating charge would be set as described above so as to insure all costs were fully compensated.

The principal problem in implementing this approach is the uncertainty as to the cost of licensing the facility. The financial risk associated with a commitment to license an inherently controversial nuclear facility of this sort may be too great to permit a two-fee, auction-implemented, user-funded mechanism to function. Further, potential users would need some assurance that a centralized facility would be available by a specific date, if they are to be able to efficiently compare the centralized storage alternative with at-reactor storage. Therefore, prior to the auction of storage rights, DOE, with the advice and assistance of NRC, should provide a realistic estimate of the licensing costs and a guarantee that licensing costs in excess of this amount would be paid for from contingency funds.

Under a *cost system*, eligibility criteria would probably be needed to insure: (1) the demand for storage could be anticipated with enough certainty to make a reasonable estimate of costs, and (2) the demand for the facility would not exceed the desired capacity limit.

If the *auction system* were used, it would be important to make the auction as competitive as possible. Effective competition usually requires a large enough number of bidders to make collusion among them difficult to arrange or enforce. In the case of utilities, the number of potential bidders is probably large enough, at least for storage in the late 1990's and beyond.[8] Under either a cost or an auction system, efficiency would be enhanced if the rights (or contracts) to store spent fuel could be bought and sold. This would allow all utilities to compare the cost of on-site storage options with the cost of centralized storage and make adjustments if warranted. It would also encourage utilities to bid in an auction system since they could sell rights at a later date if their need for storage were to change or if an increase in the price of the rights were to make it more advantageous to sell rather than use them.

Appendix I Notes

1. E.R. Johnson Associates, Inc., for Pacific Northwest Laboratory, "1988 Federal Interim Storage Fee Study: A Technical and Economic Analysis," PNL-6727/UC-85, November 1988 **(Hereafter cited as FIS Study/PNL-6727)**, p. 4–4. Costs rounded in text.

2. Golder Associates Inc., "Interim Storage Facility Cost Estimates," October 2, 1989. Costs rounded in text.

3. Nuclear Regulatory Commission, "The Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," (Rasmussen Report) WASH-1400, NUREG-75/014, October 1975.

4. See Nuclear Energy Policy Study Group, *Nuclear Power Issues and Choices*, Cambridge, Massachusetts: Ballinger Publishing Company, 1977, pp. 221–233, and Wood, William C., *Nuclear Safety Risks and Regulation*, Washington, D.C.: American Enterprise Institute, 1983, pp. 41-43, for a discussion of the WASH-1400 estimates.

5. H.W. Lewis et al., "Risk Assessment Review Group: Report to the U.S. Nuclear Regulatory Commission," NUREG/CR-0400, September 1978.

6. Department of Energy, "Monitored Retrievable Storage Submission to Congress," DOE/RW-0035/1, Rev. 1, March 1987, Vol. III, pp. 5.1-5.3.

7. FIS Study, PNL-6727, November 1988, and previous years.

8. The number of sites projected to require dry storage if an MRS or a repository is not available increases from 12 in 1995, to 32 in 2000, to 44 in 2005.

Appendix J
Managing Spent Fuel Transportation Risks

This appendix describes the risk management and regulatory rationale for, and the historical safety performance of, spent fuel transportation.

Section One: Risk Management and Regulatory Rationale

Two Federal agencies—the Department of Transportation (DOT) and the Nuclear Regulatory Commission (NRC)—have authority to regulate radioactive waste transportation. DOT, under the Hazardous Materials Transportation Act, has the authority to establish standards for safety aspects of the transport of all hazardous materials in interstate and foreign commerce, including spent fuel.[1] DOT sets standards for routing, vehicle safety, and driver qualifications and sets standards and specifications for packaging of radioactive materials. NRC has authority under the Atomic Energy Act of 1954 to regulate the receipt, possession, use, and transfer of radioactive materials.[2] NRC establishes performance standards for transportation packaging for highly radioactive materials, certifies casks, establishes safeguards requirements to prevent sabotage of shipments, and approves shipment routes. To avoid duplicate or conflicting regulation, DOT and NRC agreed in an interagency Memorandum of Understanding that DOT would defer to NRC on setting standards for shipping casks for spent fuel and other high-level radioactive materials and would incorporate NRC standards into its transportation regulations.[3]

The Department of Energy (DOE) manages the spent fuel disposal program and will be responsible for transporting spent fuel to a repository and/or MRS when one is available. Part of that responsibility includes providing assistance to State and local governments in preparing for transportation emergencies involving spent fuel.

States and some local jurisdictions regulate and inspect hazardous material transportation to varying degrees. In particular, State and local governments are responsible for responding to accidents and other transport emergencies.

Jurisdictions may overlap and regulations conflict. However, whoever is responsible for regulating or managing the transportation of any hazardous material, including spent fuel, must consider four elements:

Hazard identification;

Hazard containment;

Operational controls to reduce risk; and

Emergency response in case of an accident.

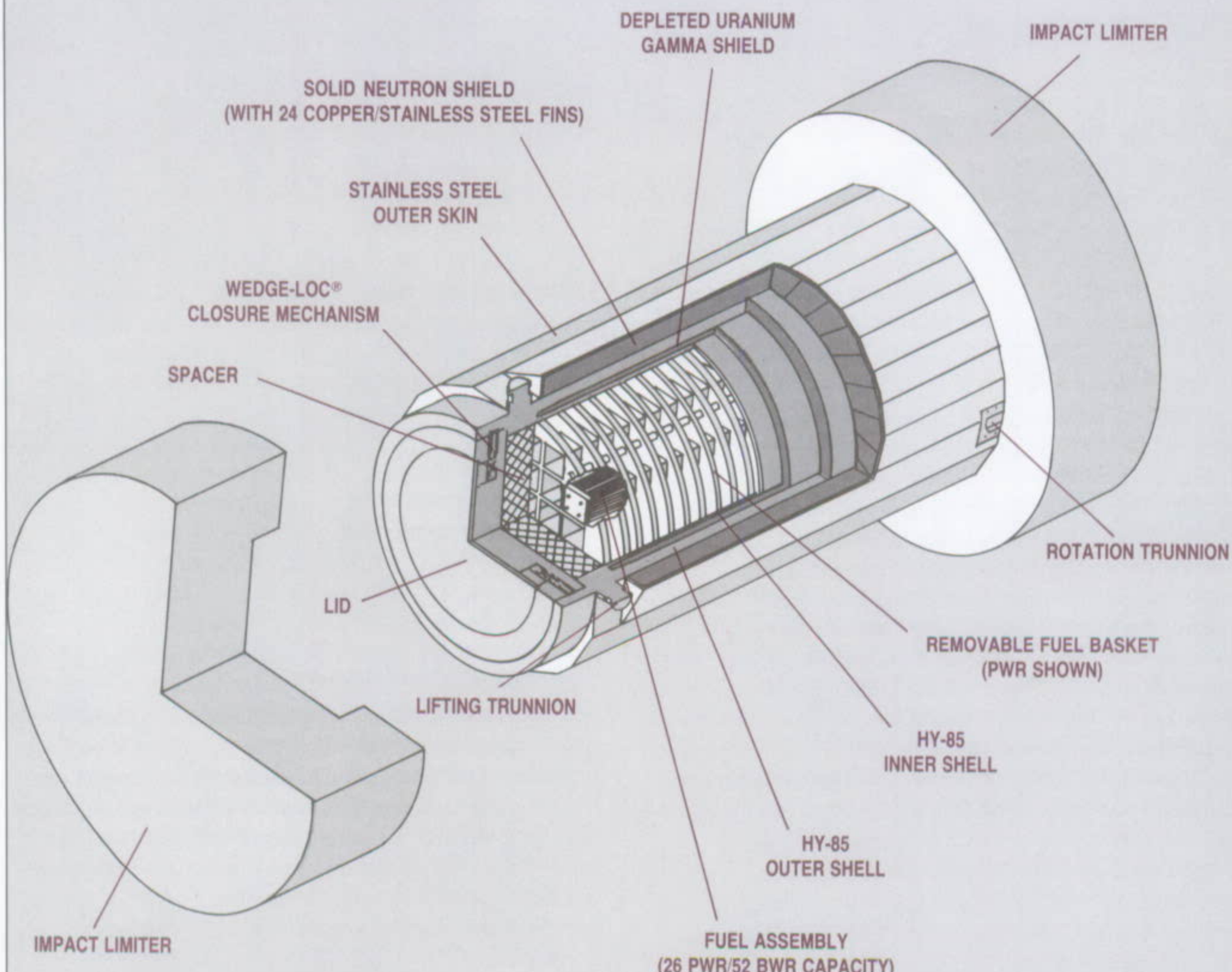
A. Hazard Identification

The specific hazard of spent fuel, radioactivity, is easily identified. Spent fuel emits ionizing radiation, which can harm living tissue, causing delayed effects, such as cancer, or, at very high exposures, immediate death. When first removed from a reactor core, spent fuel is also thermally very hot. Spent fuel is also heavy. Its weight, combined with that of the material necessary to shield it, increases the difficulties of handling and transporting it.

B. Hazard Containment: The Transportation Cask

Before being transported, radioactive material is placed in transport casks. These casks are the primary device relied upon to prevent routine or accidental release of radiation. They are massive cylindrical structures, weighing from 20 to 100 tons, designed to be sufficiently dense and thick to shield the radiation and strong enough structurally to survive an accident without releasing radioactivity. The casks are made of two 1- to 2-inch thick concentric stainless steel shells, between which is yet another layer of heavy metal, such as lead or depleted uranium, to provide shielding. (See Figure J.1.)

Figure J.1—100 Ton Combined Transport Cask Rail/Barge



SOURCE: NUCLEAR ASSURANCE CORPORATION

1. Regulation of Casks

a. Accident Protection

Regulatory standards concerning accident protection for spent fuel shipping casks prescribe specific engineering test conditions for shipping casks.[4] The specified test conditions include free fall, puncture, fire, and water immersion. These test conditions are designed to be engineering representations of the mechanical, thermal, and hydrostatic forces that may be encountered in severe transportation accidents. The specified conditions are more severe than those encountered in the vast majority of accidents. For example, the most likely kind of fire in an accident would be a pool fire in which the cask would be heated principally from one side, allowing some of the fire's heat to be dissipated into the air. The fire test standard requires the cask to be placed in an all-engulfing fire totally enveloping the cask so that no heat can be dissipated into the air. Although not impossible, this situation is unlikely to arise in a transportation accident.

According to the regulations, the tests may be performed by computer analysis,[5] scale model testing, full-scale testing, or a combination of all three.[6] These accident protection standards are in accord with those of the International Atomic Energy Agency, which are applied worldwide. A study sponsored by the Nuclear Regulatory Commission (commonly referred to as the "Modal Study")[7] concludes that 99.4 percent of transportation accidents that could involve a spent fuel cask would result in no release or releases so small that they would be below NRC regulatory standards and thus would pose no significant risk. Accidents with more severe consequences are conceivable, but they occur with decreasing probability.

b. Emissions Under Normal Conditions

Regulations for spent fuel shipping casks specify permissible levels for external radiation. (These standards apply to all radioactive material transport packages.)[8] External radiation may not exceed 200 millirem per hour anywhere on the surface of the package. The transport index—the maximum radiation level, in millirem per hour measured one meter from the package—should not exceed ten.[9] Compliance with these external radiation limits is required regardless of how much radioactive material the cask carries.

Therefore, the more radioactive material the cask carries, the smaller is the allowed external dose permitted per unit of material shipped. That is, if a certain amount of spent fuel is put in one big cask, as opposed to, say, five small casks, the total external dose permitted by regulation would be five times smaller than if that same spent fuel were put into the five small casks. This logic—that using fewer bigger casks would, under current regulation, result in less allowed total radiation than using smaller casks—suggests two things: (1) Trains can carry much bigger casks than trucks, because a freight car can carry a much heavier load than a truck. Thus, trains may serve better than trucks to reduce the amount of radiation emitted during normal transportation. (However, trains have associated with them much higher, non-radiological traffic fatality rates than trucks, and the non-radiological transportation risks dominate.) (2) Using the largest possible casks on trucks may serve to reduce the dosage during truck transport. However, State regulation may make the widespread and routine use of overweight trucks infeasible.

A truck weighing more than 80,000 lbs., including payload, must obtain a permit from each State in which it operates. Also, as a condition for issuing the permit for overweight trucks, a State may impose allowable axle weight, time-of-day, and other restrictions. In addition, some local governments and toll authorities may establish standards that are more stringent than the States'. Complying with these restrictions may be difficult, or even infeasible, since some of them may conflict with one another. At this time, there is no way of gauging whether or how many States will issue overweight truck permits for the duration of the waste disposal program or what restrictions will be imposed from State to State.

C. Operational Controls

Although the transportation cask itself is the principal line of defense against accidental releases of radioactivity into the environment, other measures could reduce the risk of accidents and the magnitude of potential consequences should a release occur. These measures include operational controls, such as (1) routing, (2) inspection and enforcement, (3) driver and other vehicle operator qualifications and training, and (4) mode choice.

1. Routing

a. Criteria

Routes can be chosen to enhance safety, using the same routing considerations that apply to transportation of hazardous materials in general. A route may be chosen for its quality and low accident record; to avoid population centers in order to reduce the magnitude of the potential consequences should a release occur; or for the emergency response capabilities along the route. For radioactive materials, the total travel time is also a factor since it affects the total amount of radiation received, especially by the crew.

These routing criteria often conflict. For example, avoiding population centers usually means increasing travel distance and time, which increases the radiation exposure

7 0 2 3 0 2 2 1 1

to the crew and may increase exposure to the public and increase traffic fatalities. Avoiding population centers may also mean traveling on lower quality roads or tracks. This is especially the case with rail transport since the railroad routes with the higher quality tracks are usually the ones which connect centers of economic activity and population concentration.

b. Regulations

DOT, which has the authority to set routing standards, has done so only for trucks, not for trains, and only for highly radioactive materials, including spent fuel.[10] Except for local pick-up and delivery and unforeseen emergencies, motor carriers are to transport the spent fuel on a system of "preferred routes." These are to consist of the Interstate Highway System and alternate routes designated by States in lieu of, or in addition to, the Interstates. The alternative route selection process requires a comparative risk analysis of the routes being examined and requires consultation with affected jurisdictions.[11] In addition to this system of routes, the carrier is required to use the Interstate bypass or beltway around a city whenever one exists. Once on the prescribed system, the only allowed criterion for route choice within the system is reduction of transit time.

Many States, especially in the West, are urging the Department of Energy to begin selecting highway routes well in advance of the disposal program's shipments.[12] Early knowledge of routes would permit States along the routes to begin contingency planning and preparations for responding to emergencies.

2. Inspection and Enforcement

The responsibility for inspection and enforcement is shared among Federal regulatory agencies and the States. Different enforcement officials inspect shipments for one or both of two purposes: traffic safety and safety from the specific hazards of spent fuel.

Both the Federal Highway Administration (FHWA) and the Federal Railroad Administration (FRA) of the DOT have inspection programs to determine compliance with general requirements covering their respective regulated carriers. These cover facets of carrier operations, such as vehicle brakes, track condition, and hours of service for truck drivers.

There is no Federal highway inspection program specifically directed to spent fuel shipments, but State highway patrols do carry out routine inspections to assure that trucks meet Federal requirements for highway transport. On the other hand, it has been the FRA's practice in recent years to make inspections specifically directed to rail transportation of spent fuel. The track along the entire route is inspected at the beginning of each shipping program (or campaign), and re-inspected at six-month intervals. The rolling stock—the locomotive, cask cars, buffer cars, and caboose—is inspected before each shipment.

NRC's practice has been to inspect for compliance at the licensee facility at the beginning of each major campaign. Once the series of shipments is underway, NRC does not routinely inspect every shipment.

3. Driver Qualifications and Training

Federal requirements for driver qualifications for highway freight carriage in general also apply specifically to radioactive materials carriage. Requirements for general motor freight carriage include commercial license standards, driver qualifications, and driving-under-the-influence of alcohol thresholds.[13] In addition, before qualifying for transporting spent fuel, drivers must have had training on the regulatory requirements for radioactive material transport, the nature of the hazard, and emergency procedures.[14] There are no analogous, radioactive material-specific training requirements for train crews.

4. Mode Choice

Choosing whether to use trucks or trains may be considered another operational safety measure, but the choice to reduce hazard is not always obvious, because while shipping by train may reduce total normal transport dose, it may incur higher traffic fatalities.

D. Emergency Preparedness

If a release does occur, effective emergency response can mitigate the consequences of an accident. Since a transportation accident can occur anywhere, preparedness is an issue of high concern to State, Tribal, and local officials, especially those in regions in the potential pathways of repository program shipments. This concern is heightened in the West where some States lie in a corridor of shipments from the East to the proposed repository in Nevada.

Some State and local governments and Indian Tribes believe they are ill-prepared to respond to a spent fuel transportation accident and cannot afford to develop a capability. These concerns were often expressed at the Commission's public hearings.[15] Some States want DOE to designate, well in advance, routes to be used in the waste disposal program so they can begin the preparatory planning process to develop an emergency response capability. Some States, such as Illinois and Colorado, have passed laws that exact fees for shipments of spent fuel through or within their States to pay for radiological safety programs.

DOE provides some technical and financial emergency preparedness assistance to States. Section 180(c) of the

Nuclear Waste Policy Act (NWPA),[16] as amended, requires DOE to provide technical and financial assistance for training purposes to States through which the spent fuel shipments will pass. In the Waste Isolation Pilot Plant program, the DOE repository program for defense transuranic waste, DOE has provided emergency response training assistance to five corridor States affected by the anticipated shipments.[17]

Apart from DOE, which is directly involved as the manager of the spent fuel disposal program, the customary Federal role has been one of coordination and technical and financial assistance. The lead Federal agency for this function is the Federal Emergency Management Agency (FEMA), whose responsibility includes response to emergencies of all kinds. FEMA has developed a guide for State and local planning for emergency response to radiological transportation accidents.[18] Otherwise, spent fuel transportation accidents are generally addressed only as a part of broader programs of training and financial assistance.

Section Two: Spent Fuel Transportation Safety Performance

Spent fuel has been shipped routinely for some time: in the past 30 years approximately 6,500 spent fuel assemblies have been shipped in the United States.[19] From 1982 through 1988, according to a Department of Transportation data base, there have been about 1,000 spent fuel shipments.[20] The volume of spent fuel traffic is extremely small compared to the more than one billion tons of hazardous materials of all kinds transported annually. The number of spent fuel shipments will remain small even when the routine shipments from reactors begin. These shipments should number no more than 1,000 per year.

Federal government programs have been responsible for a major share of recent spent fuel transport.[21] These activities included shipments of spent fuel from certain utilities to government facilities for the civilian spent fuel disposal programs demonstration projects such as rod consolidation; the court-ordered return of spent fuel from the West Valley, New York, reprocessing plant to the original utilities; and the transport of Three Mile Island debris to Idaho. Activities in the private sector have included intra-utility shipments, such as those between Duke Power Company's Oconee and McGuire plants, and shipments from some reactors, such as Monticello, to the General Electric storage facility at Morris, Illinois.

The safety performance of spent fuel transportation has been good and is consistent with the performance predicted by risk analyses. In 1971, DOT started an incident-reporting requirement for hazardous materials, entering data into a computerized data base, the Hazardous Materials Information System. In the 14 years from January 1971 to March 1985, four transportation accidents occurred involving spent fuel shipping casks and one empty cask. One driver died from the injuries sustained in one of the accidents, but no radioactivity was released in any of the accidents.[22]

In its study on transportation of hazardous materials, the Office of Technology Assessment of the U.S. Congress found "technical evidence and cask performance in service indicate that NRC performance standards yield spent fuel shipping cask design specifications that provide an extremely high level of public protection, much greater than that afforded in any other current hazardous materials shipping activity. However, meticulous adherence to the designs during cask manufacture and to required safety procedures during loading and transport are critical factors in ensuring public and environmental safety."[23]

Appendix J Notes

1. 49 U.S.C. 1801–1812.

2. 42 U.S.C. Chapter 23.

3. Transportation of Radioactive Materials, Memorandum of Understanding, 44 FR 38690 (July 2, 1979).

4. 10 CFR 71.73.

5. Computer models have been validated by full-scale tests in the late 1970s.

6. 10 CFR 71.41.

7. Nuclear Regulatory Commission, "Shipping Container Response to Severe Highway and Railway Accident Conditions," Volume 1, NUREG/CR-4829, February 1987, p. 9–28.

8. Most radioactive materials are carried in what is referred to as Type-A packages, which have far less stringent regulatory requirements than Type-B packages, the packaging required for shipping spent fuel. Some materials, such as smoke detectors, are so low in radioactivity content that the only packaging requirement is a "strong tight" container.

9. 10 CFR 71.47.

10. 49 CFR 177.825.

11. Other than this designation role, States have little room to maneuver in the routing regulations because of the potential for Federal preemption.

12. Western Interstate Energy Board, "Resolution of the Western Interstate Energy Board," adopted March 1988.

13. Office of Technology Assessment, "Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment," OTA-SET- 382, September 1988, p. 57.

14. 49 CFR 177.825(d).

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Appendix K
Glossary, Acronyms, and Abbreviations

AEC: Atomic Energy Commission. Its functions have been assumed by DOE and NRC.

AFR: Away-from-reactor storage. Spent fuel storage outside a reactor site boundary. Normally used for receipt and interim storage of irradiated fuel from several nuclear power plants.

ALARA: "As low as reasonably achievable." A radiation protection principle, held by national and international scientific and regulatory authorities, and applied to radiation exposures. The term means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.

At-reactor storage: Spent fuel storage that is integral with a reactor, or situated within the site boundary of a nuclear power station.

Background radiation: Nuclear radiation due to the natural environment and to naturally occurring radioactivity within the body.

Beta particles: A charged particle that is emitted by certain radioactive materials and is physically identical with the electron.

Boiling water reactor (BWR): A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam is used directly to drive a turbine to generate electricity.

Burnup: A measure of consumption of fissile content of reactor fuel, expressed as either the percentage of fuel atoms that have undergone fission, or the amount of energy released per unit mass of nuclear fuel in the reactor. Units normally used for the latter are megawatt-days per ton of uranium or heavy metal.

Canister: The first material envelope surrounding a waste form (e.g., spent fuel rods) to provide containment for storage and handling purposes.

Carrier: A company engaged in transporting high-level waste or spent fuel by land or water.

Cask: A massive container used to transport and/or store irradiated nuclear fuel. It provides physical and radiological protection and dissipates heat from the fuel.

Cask, dual-purpose: A cask that could serve as a storage module as well as a transport cask.

Cask, universal: A cask that could be used for spent fuel storage, transportation, and emplacement in the repository without further repackaging or overpacks.

CFR: Code of Federal Regulations.

Characterization: The collecting of information necessary to evaluate suitability of a region, location, or site.

Cladding: An external layer of material (usually of Zircaloy or stainless steel) directly surrounding nuclear fuel that seals and protects it from the environment, and protects the environment from radioactive materials produced during irradiation.

Commercial nuclear reactor: A civilian nuclear power plant, owned by an electric utility or utilities, and operated for generating electricity for commercial sale. It is required to be licensed by the NRC.

Consolidation: The operation performed on spent fuel assemblies during which the non-fuel bearing components (upper and lower fuel-assembly tie plates, assembly spacer grids and any other assembly structural members) are removed and reduced in volume, and the fuel rods are collected and formed into a closely packed bundle for insertion into a canister, to achieve volume reduction, thereby reducing the space required for storage, transportation or disposal.

Container: A receptacle designed to hold a canister of spent fuel or radioactive material to facilitate movement and storage.

Criticality: A self-sustaining neutron chain reaction in which the number of neutrons lost by absorption or leakage just equals the number produced by the fission process.

Decommissioning: The process of removing a nuclear facility from operation and returning it to a condition where it can be released for unrestricted use. Its contents may be decontaminated and dismantled, or decontaminated and converted to another use. This process occurs over a period of several years.

Dedicated train: A train purposefully configured and operated to serve a specific function, such as to move a certain commodity, to use a certain type of equipment, or to handle traffic by a certain shipper. Dedicated trains are different from "regular trains," which generally transport many commodities using many types of equipment for many different shippers.

Disposal: Emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste.

DOE: U.S. Department of Energy.

Dose equivalent: A quantity used for radiation protection purposes that expresses on a common scale for all radiations, the irradiation incurred by exposed persons. It is defined as the product of the absorbed dose and the quality factor, a measure of the biological effectiveness of the radiation which produced the dose. Its unit is the rem or sievert.

DOT: U.S. Department of Transportation.

Dry storage: Storage of spent nuclear fuel, in a canister or not, surrounded by one or more gases such as helium, air, nitrogen or carbon dioxide, in cask, drywell, silo or vault systems. Dry storage is passive, modular, and low in maintenance, and provides an alternative for nuclear power plants that cannot accommodate additional storage in spent fuel pools.

EIS: Environmental impact statement.

Enriched fuel: Nuclear fuel containing uranium which has been enriched in its fissile isotopes or to which chemically different fissile nuclides have been added. Commercial nuclear power plants in the United States use uranium which has been enriched so that it contains 2-5 percent U-235.

EPA: U.S. Environmental Protection Agency.

ERDA: Energy Research and Development Administration. With NRC, successor to the U.S. Atomic Energy Commission. Predecessor to the Department of Energy.

Federal Emergency Storage Facility (FES): A facility to serve as a safety net of storage for spent nuclear fuel for emergency purposes.

Federal Interim Storage Facility (FIS): A Federally owned and operated facility possibly located at an existing Federal site, that would provide storage for spent nuclear fuel from civilian reactors whose owners cannot reasonably provide adequate storage capacity on-site. The Nuclear Waste Policy Act currently limits the capacity of such storage to 1,900 metric tons.

Fertile isotope: An isotope capable of being transformed into a fissile isotope by neutron capture at specific neutron energies.

Field drywell: Stationary, below-ground, lined individual cavities to store spent fuel. Shielding is provided by the surrounding earth and a shield plug. Heat dissipation is by conduction through the earth to the atmosphere.

Fissile isotope: An isotope in which neutrons of any energy can induce fission.

Fission products: A general term for the complex mixture of nuclides produced as a result of nuclear fission.

Fuel assembly: A geometrical array of fuel rods, pins, plates, etc., held together by structural components for insertion in a reactor. Also called fuel bundle, fuel cluster, and fuel element.

Gamma ray: Short wave-length electromagnetic radiation emitted during the radioactive decay of certain nuclides.

Half-life: Time during which half of the atoms of a radioactive substance undergo radioactive decay. Half-lives vary from millionths of a second to billions of years. After a period equal to 10 half-lives, the radioactivity has decreased to about 0.1 percent of its original value.

High-level waste: The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste, that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation. In the United States spent nuclear fuel is considered to be high-level waste.

Highway route controlled quantity: Amount of radioactivity within a certain type of package that makes the package subject to DOT highway routing requirements. Spent nuclear fuel would be a highway route controlled quantity of radioactive materials.

Independent spent fuel storage facility (ISFSF): A wet or dry storage facility located separate from a nuclear power plant or fuel reprocessing plant. An ISFSF located at the site of another facility (e.g., a reactor) is considered independent, even if it shares utilities services or physical protection, provided that it does not affect the safety of the other nuclear installation.

Integral MRS: MRS facility which would receive and eventually ship to the repository all spent fuel requiring permanent disposal, and thus integrate the MRS into the Federal waste management system. In the integral MRS, there may be a "Western Strategy" in which the spent fuel from western reactors would go directly to the repository.

Interim storage: Storage of radioactive materials such that (a) isolation, monitoring, environmental protection and human control are provided; and (b) subsequent action involving treatment, transport, and disposal or reprocessing is expected.

Ionizing radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

IRG: Interagency Review Group on Nuclear Waste Management. Established in 1977, it submitted its report on nuclear waste management to President Carter in 1979.

Light water reactor: A nuclear reactor that uses light (ordinary) water to moderate (slow down) high-velocity neutrons and remove heat from the reactor core.

Low-level waste: Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11(e)(2) of the Atomic Energy Act.

Metric ton: 1,000 kilograms; about 2,200 pounds.

Metric tons of uranium (MTU): That measure of weight equivalent to about 2,200 pounds of uranium loaded into a reactor as fresh fuel.

Millirem: One-thousandth of a rem. In the International System of Units this would be equal to 0.00001 sieverts. (See definition for **rem**)

MRS: Monitored retrievable storage. Storage of spent fuel or high-level waste in facilities that provide sustained monitoring capability and retrievability.

NEPA: National Environmental Policy Act of 1969.

NRC: U.S. Nuclear Regulatory Commission. With ERDA, successor to U.S. Atomic Energy Commission.

NTS: Nevada Test Site.

Nuclear Waste Fund: Fund established by the Nuclear Waste Policy Act of 1982 to assure that the costs of high-level radioactive waste management and disposal are borne by the owners and generators of the waste. At present, the owners and generators pay into the Waste Fund a fee of one mill per net kilowatt-hour of nuclear-generated electricity.

NWPA: Nuclear Waste Policy Act of 1982.

NWPAA: Nuclear Waste Policy Amendments Act of 1987.

OCRWM: Office of Civilian Radioactive Waste Management, in the Department of Energy.

Overpack: A secondary external enclosure for packaged spent fuel providing additional protection.

Packaging: The act of preparing spent nuclear fuel for handling, storage, shipment, and/or disposal. A cask or overpack may be a permanent part of the package.

Person-rem: A unit of population dose equivalent obtained by multiplying the dose equivalent in rem by the population exposed. In the International System of Units, this would be expressed in person-sieverts.

Plutonium: A heavy element (atomic no. 94) which comprises about 1 percent of spent nuclear fuel from commercial light water reactors. One of the principal fissile isotopes of plutonium is Pu-239 which has a half-life of about 24,000 years.

Pressurized water reactor (PWR): A light water reactor having primary and secondary cooling circuits. In the primary circuit, heat is transferred from the reactor core to a heat exchanger by means of water kept under high pressure to achieve high temperature without boiling; in the secondary circuit, steam is produced to drive turbines to generate electricity.

Radioactive decay: Spontaneous decay or disintegration of an unstable atomic nucleus, accompanied by the emission of ionizing radiation.

Radionuclide: An unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

Rem: The unit of dose equivalence commonly used in the United States. In most countries the rem has been replaced by the sievert, which is the unit of dose equivalent in the International System of Units. A sievert is equal to 100 rem.

Repository: A facility for the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel. It includes both surface and subsurface areas where high-level radioactive waste and spent nuclear fuel handling activities are conducted.

Reprocessing: Recovery of fissile and/or fertile material from irradiated nuclear fuel by chemical separation from fission products and other radionuclides (e.g., activation products, actinides); selected fission products may also be recovered.

Reracking: Replacement of existing fuel storage racks with modified racks designed to increase the amount of spent fuel that can be stored in pools at reactor sites.

Retrievability: Capability of spent fuel or high-level waste to be removed from where it has been stored or disposed.

Risk: Possibility of suffering harm or loss. The magnitude of the risk depends on both the probability of occurrence of an event and the expected consequences should the event occur.

Safeguards: Includes physical protection and material accountability. Physical protection is protection against sabotage of spent fuel. Sabotage is a deliberate, malevolent act that could result in high environmental radiation levels or release of radioactive materials to the environment. Material accountability is protection against undetected theft or diversion of the fissile material in spent fuel.

Shipping cask (transport cask): A container to transport spent fuel and other radioactive wastes. It provides physical and radiological protection, and dissipates heat from the fuel during shipment.

Spent nuclear fuel: Irradiated fuel element not intended for further reactor service.

Storage: Retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal.

Transuranic waste: Waste material contaminated with plutonium and other elements having atomic numbers higher than 92. In the commercial fuel cycle, transuranic waste is produced primarily from the reprocessing of spent fuel and the manufacture of mixed uranium-plutonium fuel.

User-Funded Interim Storage (UFIS): Voluntary storage of spent nuclear fuel by utilities who (1) do not have space at their reactor for life-of-plant-storage, or may not be able to obtain a license for additional storage; (2) have shutdown reactors at sites where they no longer operate nuclear power facilities; (3) prefer to ship spent fuel to this facility than retain it on-site.

Uranium: A naturally occurring radioactive element with the atomic number 92 that has become the basic raw material of nuclear energy.

Vitrification: The conversion of high-level waste materials into a glassy or noncrystalline solid for subsequent disposal.

WIPP: Waste Isolation Pilot Plant. A facility for geologic disposal of transuranic waste from defense-related activities. The WIPP is located near Carlsbad, New Mexico.

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