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Centralized Interim Storage of Nuclear Waste and a National Interim Storage Strategy

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ABSTRACT

As radioactive spent nuclear fuel accumulates at nuclear power reactors around the country, it becomes increasingly important to develop a national interim storage strategy to manage spent fuel while permanent disposal facilities are being developed. This report examines the advantages and disadvantages of using centralized interim storage, and determines how centralized interim storage fits into a national interim storage strategy. This report also considers the federal government's interest in centralized storage and its role in creating an optimized interim storage system for future nuclear reactors. It offers several recommendations concerning the implementation of an optimized interim storage system and outlines the major policy issues that need to be addressed.

Preface

About the Author

Robert Petroski is a fourth-year undergraduate at the University of California, Berkeley. He will graduate in May 2006 with Bachelor of Science degrees in nuclear engineering and engineering physics. Last summer, he worked for Professor Per Peterson, Chair of the UC Berkeley Nuclear Engineering Department, on a project studying the material inputs of different nuclear reactor designs. On campus, Robert is involved with the engineering honor society Tau Beta Pi, the Berkeley student chapter of the American Nuclear Society, and the Multicultural Student Union. Some of his interests include sporting events, food, games, and mathematics. He plans on pursuing an advanced degree in nuclear engineering after graduation.

About WISE

The Washington Internships for Students of Engineering (WISE) program is an intensive nine-week program designed to expose a group of engineering students to public policy. The program's goal is to create future leaders in the engineering profession who are aware of and can contribute to the important intersections of technology and public policy. Each student, sponsored by a professional engineering society, visits with leaders in the Congress and the Administration, industry, and prominent non-governmental organizations in order to learn how decisions are made on complex technological issues. During the program, students are encouraged to research a topical technological public policy issue and create a report detailing their findings. These reports, along with more information about the WISE program, can be found online at http://www.wise-intern.org/. This multi-society program is supported by the American Association of Engineering Societies.

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Introduction

Nuclear energy currently generates approximately twenty percent of all electricity used in the United States. Recently, there has been increasing interest in nuclear energy, stemming partly from growing concerns about global climate change. Because nuclear energy is a low emissions, high capacity, and economically competitive power source, it is seen as potentially essential for plans to curb greenhouse gas emissions and avert climate change. Additionally, new nuclear reactor technologies are being developed that have the potential to make nuclear energy safer, cheaper, and applicable towards additional purposes such as hydrogen generation. As a result, there is a building expectation that nuclear energy will see renewed growth in the coming decade.

An inevitable byproduct of nuclear energy is the creation of highly radioactive spent nuclear fuel. This spent fuel remains radioactive for hundreds of thousands of years, so it must be properly disposed of to prevent future harm to the public and environment. While plans for the disposal of spent fuel have been developed, so far none have been successfully implemented. Therefore, spent fuel must be properly managed and stored until disposal options become available. The storage of spent fuel between the time it leaves a reactor and the time it is disposed is referred to as interim storage. If nuclear energy is to experience an expansion, a proper interim storage strategy must be developed that can manage spent fuel in a safe, secure, and cost effective manner.

This report examines the concept of centralized interim storage and how it fits into a national interim storage strategy. First, it considers the differences between centralized interim storage and at-reactor storage in the areas of economics, safety, and security. Then, it describes the federal government's interest in interim storage in terms of policy goals and policy barriers, and concludes with recommendations for an optimal interim storage strategy. These recommendations describe the role centralized interim storage should play in future management of spent nuclear fuel and outline actions needed to create an optimized interim storage system.

Background

Overview of nuclear waste issues

Each year, United States nuclear reactors finish burning approximately 2,000 metric tons of uranium fuel, creating an equivalent amount of spent nuclear fuel.[1] Because spent fuel contains radioactive fission fragments, it is radioactive, thermally hot, and potentially hazardous to people and the environment. Therefore, it is important to properly store, transport, and dispose of spent nuclear fuel so that public and environmental exposure to radiation is minimized. Furthermore, because spent nuclear fuel remains radioactive for hundreds of thousands of years[2], any sensible spent fuel management plan must limit exposure at timescales ranging from the short-term to the very long-term.

In the Nuclear Waste Policy Act of 1982 (NWPA)[3], the United States federal government outlines a national plan for the long-term management of high-level radioactive waste, which includes spent nuclear fuel accepted for disposal[*]. In the NWPA, the government acknowledges its responsibility for the permanent disposal of high-level waste, and directs the U.S. Department of Energy (DOE) to characterize the suitability of different sites for serving as a permanent geologic repository. In 1987, the NWPA was amended to name Yucca Mountain, Nevada as the single candidate site for study as the nation's high-level waste repository.[4] To pay for the study and development of a repository, the act established the Nuclear Waste Fund, funded by a ratepayer fee of one mill (0.1 cents) per kilowatt-hour of nuclear generated electricity.

Neither the original 1982 NWPA nor the amended version specifies a federal policy regarding near-term management of spent fuel. Instead, the act designates the producers and owners of spent nuclear fuel responsible for its interim storage until the federal government is ready to accept it for permanent disposal. However, it statutorily guarantees that, in exchange for the nuclear waste fee, the Department of Energy would begin accepting and disposing waste no later than January 31, 1998. This deadline passed without an available federal facility, and the federal government thus defaulted on its obligation to accept spent fuel. Utilities, as a result, have continued to provide for the interim storage of spent fuel, and some have tried to hold the government liable for the additional cost of this storage[5].

While Congress and the President approved the development of a geologic repository at Yucca Mountain in 2002, the technical and political obstacles facing the licensing of such a repository have proven to be far greater than originally envisioned. Significant delays in the Yucca Mountain Project have resulted, and current predictions are that Yucca Mountain will not begin accepting waste until 2012 at the earliest[6]. Nuclear utilities therefore must extend both the capacities and lifetimes of their interim storage facilities as spent fuel continues to accumulate at reactors without a means of permanent disposal available.

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[*]Because spent fuel still contains potentially useable uranium and plutonium, it is not characterized as waste until it is accepted for disposal. At this point, spent fuel is characterized as high-level radioactive waste, and some sources will use the two terms interchangeably.

Overview of Interim Storage

Current interim storage infrastructure

Currently, utilities employ two methods of storing spent nuclear fuel: spent fuel pools and dry cask storage. Spent fuel in each of these systems is a ceramic solid kept in bundled rods called fuel assemblies, the same form it assumes when it is originally loaded into a reactor. The first storage system, spent fuel pools, is used at all 103 operating nuclear reactors, and remains in service at an additional 15 shutdown reactor sites.[7] They store approximately 43,900 MTU* of spent fuel, and have a total capacity of approximately 61,000 MTU.[8] These fuel pools maintain spent fuel assemblies below at least a twenty foot depth of circulating water, which acts as both a coolant and shielding material for the spent fuel. During nuclear power plant construction in the United States, it was anticipated that spent nuclear fuel could be sent to a reprocessing facility within a few years of being removed from a reactor core, so spent fuel pools were sized according to this expectation.[9] After reprocessing plans were abandoned in the 1970s, pool capacities were insufficient to properly manage all of the spent fuel generated over reactor operating lifetimes. While measures have been taken to maximize pool capacities, such as re-racking fuel assemblies and fuel rod consolidation, spent fuel pools at 42 operating reactor sites have reached maximum storage capacity as of the end of 2004,[10] and 78 are expected to reach capacity by 2010.[11] It is generally impractical to expand existing fuel pool capacities because pools are integrated into plant building structures, and plant layouts generally do not allow for additional building space. To address the need for additional spent fuel storage capacity, dry cask storage systems were developed and implemented.

After spending approximately five years cooling in a spent fuel pool, spent fuel may be transferred into containers for dry, aboveground storage, referred to as "dry cask storage" or simply "dry storage." While dry storage systems may take a number of configurations, they all involve placing spent fuel into extremely heavy concrete and metal casks or vaults. These containers are then kept aboveground at facilities called independent spent fuel storage installations (ISFSIs). Like spent fuel pools, existing ISFSIs are located at reactor sites, so commercially generated spent fuel is stored exclusively at reactors.† Currently, dry cask storage is licensed at 34 installations in 24 states, with an additional 14 sites being planned. Approximately 7,300 MTU of spent fuel is stored at these ISFSIs[12].

As spent fuel inventories continue to grow, increasing attention has been given to alternatives to strictly at-reactor storage of spent fuel. One option being currently considered by government and industry is the storage of spent nuclear fuel at one or several centralized sites.

Centralized interim storage

Centralized interim storage involves storing spent fuel generated at different reactor sites at a large, central storage facility, usually independent of an operating nuclear reactor. A centralized

* MTU stands for metric tons uranium, defined as the amount of spent fuel created by burning one metric ton of uranium. This is different from the actual mass of the material being stored. For commercial power reactors MTU is equivalent to metric tons heavy metal (MTHM), and both are sometimes abbreviated as MT. MT, MTHM, and MTU are often used interchangeably when discussing spent fuel quantities.

† A small portion of commercially generated spent fuel is located at two small private storage sites located at former reprocessing plants. These sites do not accept spent fuel, and are not pertinent to the content of this report.

interim storage facility would resemble a large-scale dry cask storage installation, accompanied by necessary handling facilities and transportation infrastructure. Spent fuel destined for such a site would be loaded at its origin site into a transportation container, transported by rail or truck to the central site, then unloaded and placed in a dry cask or vault for storage.

There are varying degrees to which centralized storage can be applied. A smaller centralized storage facility may be used simply as an alternative destination for spent fuel leaving a spent fuel pool. Alternatively, a more extensive facility may be used to consolidate all existing inventories of spent fuel currently stored at at-reactor ISFSIs. A centralized storage facility would also need to be licensed as an ISFSI by the Nuclear Regulatory Commission (NRC), which is responsible for regulating, overseeing, and licensing interim storage[*].[13]

Advocates for centralized interim storage cite a number of potential benefits that such a system could offer. These include reduced cost, enhanced security, increased storage flexibility, and improved standardization. Additionally, advocates suggest that a centralized site may prevent early plant closures, as well as allow for earlier decommissioning of shutdown reactor sites still storing spent fuel.[14] Opponents of centralizing storage dispute these benefits, and point to concerns over transportation and storage risk, environmental impact, and site security. Opponents are also concerned that a centralized interim site may turn into a de-facto permanent site.[15]

Members of Congress have expressed interest in a federal centralized interim storage facility as a means to assume responsibility for spent fuel prior to the opening of a permanent repository.[16] This is in the interest of government because it would allow the government to avoid future liability to utilities for the cost of interim storage. Past studies have suggested that consolidating existing spent fuel inventories can also provide national security advantages and improve public confidence about the status of spent fuel.[17] Federal willingness to take title to and manage spent fuel would also increase utility confidence by removing the economic and legal uncertainties facing utilities regarding continued at-reactor interim storage.

The Private Fuel Storage proposal

With regard to the current status of centralized interim storage plans, the Private Fuel Storage (PFS) proposal stands out as being the plan closest to implementation. Private Fuel Storage LLC, a private consortium of eight nuclear utilities[†], has planned and is seeking licensing for a centralized interim storage site to be located on the Skull Valley Goshute Indian reservation in Tooele County, Utah. The PFS facility, designed to store up to 40,000 MTU of spent fuel, has successfully completed most of the licensing process, which has taken eight years to date. It is possible that PFS will receive a twenty-year renewable license from the NRC this year. Due to the extensive research and regulatory work that has been performed on the proposed PFS site, it serves as a useful example and model of centralized interim storage.[18]

The PFS storage plan does not involve consolidating all existing dry storage inventories of spent fuel at the PFS facility. Instead, the PFS facility will act as an additional storage option for utilities that require additional storage for spent fuel leaving the spent fuel pool, or wish to move spent fuel from existing dry storage to an off-site facility. The PFS facility is being licensed as

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[*] The Nuclear Regulatory Commission is responsible for all waste storage and disposal, whether or not it's interim

[†] PFS's member utilities are: Xcel Energy, Genoa Fuel Tech, American Electric Power, Southern California Edison, Southern Nuclear Company, First Energy, Entergy, and Florida Power and Light.

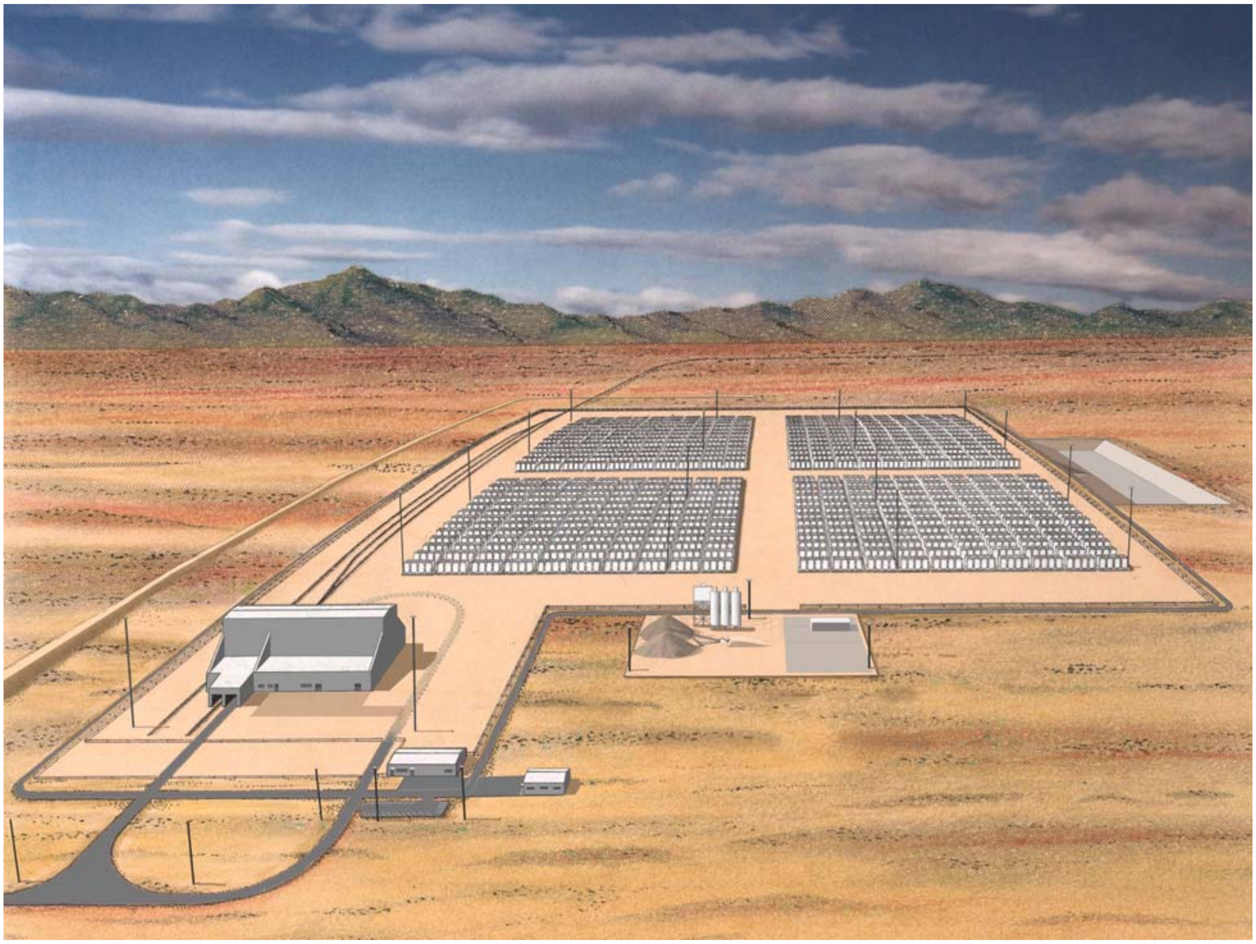

Figure 1: Artist's rendition of the proposed PFS facility in Utah, courtesy Private Fuel Storage

an ISFSI, and will be set up to accept spent fuel that is placed into canisters* and transported to the facility via rail. In addition to using PFS as a model of centralized storage, this rpoert considers some of the specific benefits, costs, and risks associated with PFS and examine how PFS fits into a national interim storage strategy.

Towards a national spent fuel interim storage plan

The alternative to creating centralized interim storage is simply the continued use of at-reactor storage, with the expansion of storage capacity and inter-site transportation where necessary. This report examines the relevant economic, environmental, safety, security, and policy factors distinguishing the use of centralized interim storage from the at-reactor alternative, using the PFS case as a model where applicable. It considers how different storage systems can be used to achieve the goal of economic, safe, and secure interim storage. Finally, this report considers what role the federal government can take in establishing a long term, national interim storage strategy that also serves wider public policy concerns.

* Additional details about dry cask storage and transportation, including specifics about canister-based systems, are provided in the cask overview section of this report.

Analysis

Brief overview of cask systems

The types of storage and transportation systems utilized in association with an interim storage facility have a direct bearing on its safety, security, and cost, and it is useful to begin with an overview of the different kinds of dry cask systems. First, all cask systems are very large and very heavy. A typical concrete storage cask can be 20 feet high, 11 feet in diameter, and weigh up to 180 tons loaded[19], while a typical metal cask used for storage or transportation can be 18 feet high, 8 feet in diameter, and weigh up to 115 tons loaded.[20] In general, dry cask systems may be grouped into several categories to reflect differences in their configurations and capabilities. Two important distinctions are those between single-purpose and dual-purpose systems, and between bare-fuel and canister-based systems.

Single-purpose systems are designed to either store or transport spent fuel, whereas dual-purpose systems may be used for both storage and transportation*. While the use of dual-purpose casks can eliminate the need for separate transportation casks, their increased cost (approximately four to five times more than that of single-purpose storage casks)[21] makes them unattractive for storing large inventories of spent fuel. For storing large inventories, such as found the U. S., it is more cost effective to use cheaper single-purpose storage casks, transferring to reusable single-purpose transportation casks as necessary. The relative ease and cost of these inter-cask transfers depends on whether a bare-fuel or canister-based system is employed.

In bare-fuel systems, fuel assemblies are placed directly into casks. In newer canister-based systems, fuel assemblies are first placed into separate thin-walled steel canisters, which are welded shut before being placed in an appropriate "overpack," which is essentially a storage or transportation cask. To transfer spent fuel between storage and transportation casks in a bare-fuel system, it is necessary to handle spent-fuel directly, which requires a specialized "hot-cell" facility and entails more cost and difficulty. Dual-purpose canisters, which may be placed in both storage and transportation casks, avoid this difficulty. Further, such canisters eliminate some of the cost (approximately 10-15%)[22] of transportation casks by eliminating the need of an interior "basket" to hold spent fuel. Canister-based storage systems are also approximately the same cost as bare-fuel storage casks.

Because of the cost and ease-of-use advantages of dual-purpose canister-based systems, there has been a shift towards using them in the U. S. Many utilities have adopted such systems at their ISFSIs[23], and PFS has planned to employ them at its proposed centralized facility.

In the discussions that follow, it is assumed that dual-purpose canister-based systems are used for all new (i.e. not currently existing) facilities. This assumption is based on the advantages such systems provide as well as the current trend towards implementing them. Because of this assumption, some of the findings in this report may not be accurate for bare-fuel systems or dual-purpose casks.

* There is a third category of system known as "multi-purpose," for cask systems that are suitable for storage, transportation, and permanent disposal in a geologic repository. However, since no spent fuel disposal facility has been licensed, disposal container requirements are not set, and no multipurpose systems currently exist. Also, disposal containers are likely to require highly specialized designs that may not be compatible with requirements for interim storage or transportation, so it is possible that no multipurpose systems will ever exist. Because of the speculative nature of multipurpose cask systems, they are not considered in this report.

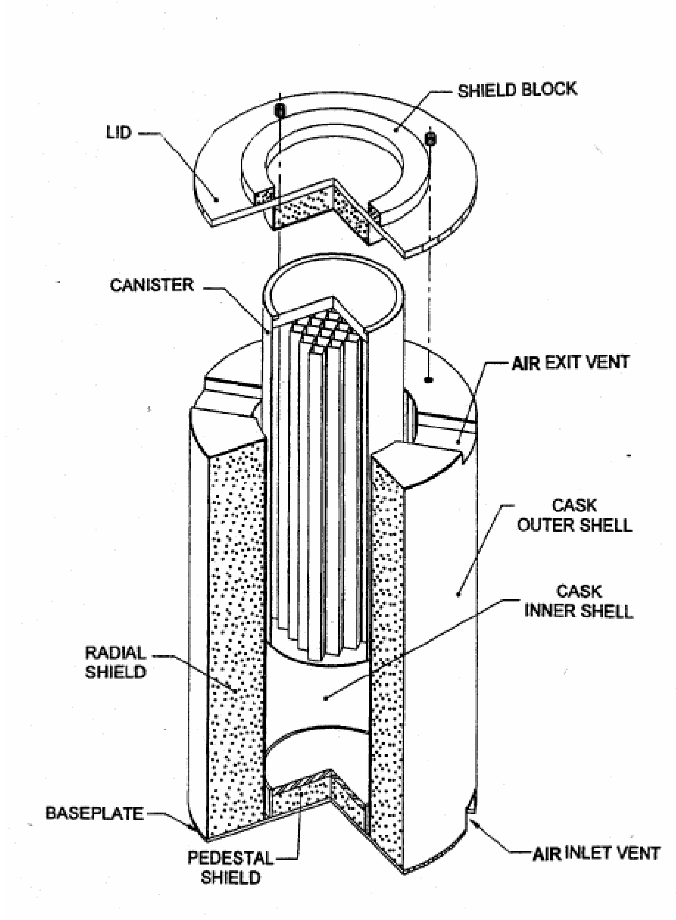

Figure 2: Diagram of a typical canister-based storage cask, the Holtec International HI-STORM-100, courtesy NRC

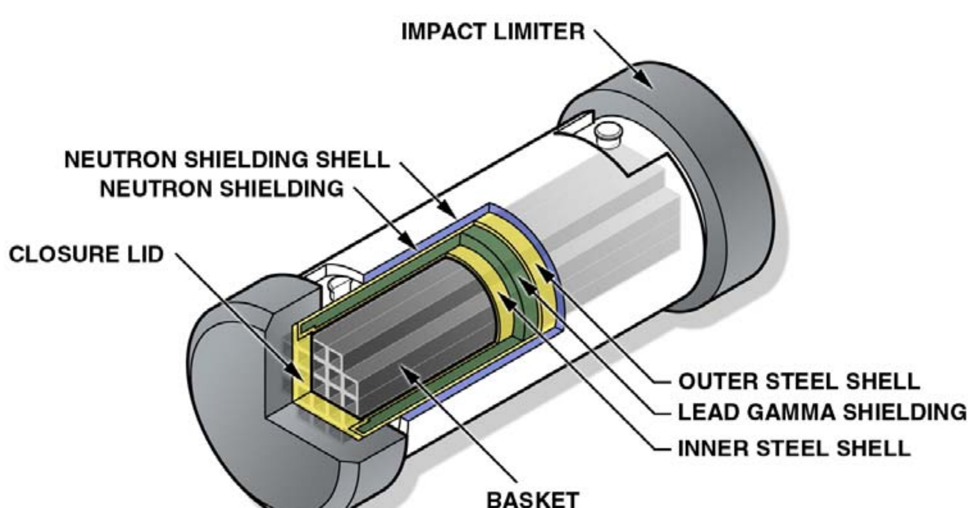

Figure 3: Drawing of a generic rail transportation cask, courtesy NRC
Note: this transportation cask does not include a canister and is therefore a bare-fuel system

Economic factors

The economics of centralized spent fuel storage is an extremely significant topic; however, it is also the area subject to the most uncertainty in this report. Nevertheless, useful, albeit tentative conclusions can be reached based on available public information.

Uncertainties in the costs and benefits of instituting centralized storage arise from two sources. First, there is a lack of publicly accessible specific cost data. Since reactor operating companies, plant constructors, and storage systems manufacturers are private companies, their costs and business plans are often kept proprietary to maintain competitive advantage. Second, the relative costs of different storage arrangements are sensitive to a large number of variables. These include particulars of the storage facility and storage casks, the mode and distance of transportation, volume and duration of storage, and economic factors such as interest rates.

Outline of method

To account completely for the cost of a given interim storage arrangement, it is necessary to track the nation's entire inventory of spent fuel, and sum up the different infrastructure and operating costs needed to package, transport, transfer, and store it. To do this requires one to predict where and when spent fuel is generated and moved, and also to predict when fuel will be moved into a permanent geologic repository or reprocessing facility. Further, one must predict changes in the incremental costs for spent fuel storage that may result from reactor decommissioning, and account for any restrictions that limit the storage capacity of a given site.

Forecasting system-wide spent fuel storage costs in this manner can become extremely complex, requiring the use of computer models to account for fuel inventories and storage capacities. Accurate results also depend heavily on the quality of available cost data, and on unknowns such as the availability of a disposal facility. Because many of these necessary data inputs are not readily available or easy to estimate, a comprehensive economic analysis in the manner described is beyond the scope of this report.

Instead, this report includes a basic economic analysis performed by comparing the costs for transporting and storing spent fuel in different interim storage arrangements, considering required infrastructure costs separately as necessary. The analysis draws from available cost estimates whenever possible; a summary of a more complete economic analysis of the proposed PFS facility is referenced for further information. This summary is found in the PFS Final Environmental Impact Statement (FEIS).[24] The FEIS considers the economics of PFS to ensure that PFS is financially capable of maintaining the safety and security of any spent fuel it accepts.

Assumptions

The costs assumed in this analysis are provided in Table 1. All costs are given in 1999 dollars, to correspond with the values in the sources used. Values for cost to accept fuel include the costs to purchase and load dry casks, assuming a large canister-based design is used, as well as transportation costs where applicable. Cost to accept fuel for the centralized ISFSIs is calculated by multiplying the at-reactor value by 70%, then adding 30,000 – 55,000 ($/MTU) and rounding. The initial 30% reduction in cost for fuel storage infrastructure is similar to that referenced in the PFS FEIS, and represents savings resulting from economies of scale.[25] The addition of 30,000 – 55,000 ($/MTU) represents costs for transportation. The 55,000 ($/MTU) value is an average based on Yucca mountain project estimates for the cost to transport spent fuel from all reactor sites to Yucca mountain, and includes the cost of transportation infrastructure.[26] This figure also includes increased costs required to meet the varying infrastructure capabilities and needs of existing reactors. Therefore, it is assumed that transportation savings may be possible if spent fuel transportation standards, such as canister standards, are applied. This results in a potentially lower average cost for transportation; the 30,000 ($/MTU) figure is used to approximate such a savings. In both cases actual transportation costs are site specific and dependent on existing infrastructure and distance transported, so specific costs may fall outside this range. The cost to accept fuel at an at-reactor site other than the generating site is calculated by adding the transportation cost of 30,000 – 55,000 ($/MTU) to the base at-reactor storage cost of 80,000 – 95,000 ($/MTU).

Finally, cost estimates for a potential federal centralized storage facility at a DOE site are also given. It is assumed that such a site would have the same cost for accepting spent fuel as an independent centralized ISFSI, but would have lower operating costs due to infrastructure (security, etc.) already present at DOE facilities. For the purposes of this economic analysis such a site may be considered equivalent to other centralized storage sites; the use of DOE facilities for centralized storage is examined further in the policy section of this report.

Table 1: Assumed cost-ranges for different storage sites

Storage site	**Cost to accept fuel ($/MTU)**	**Operating cost ($/y)**
At-reactor ISFSI (at generation site)	80,000[27] – 95,000[28]	600,000[29] – 750,000[30]
At-reactor ISFSI (not at generation site)	110,000 – 150,000	600,000 – 750,000
Centralized ISFSI	85,000 – 120,000	3,000,000 – 4,000,000[31]
Shutdown-reactor ISFSI (with fuel pool)	80,000 – 95,000*	8,000,000 – 9,000,000[32]
Shutdown-reactor ISFSI (no fuel pool)	NA	3,000,000 – 4,000,000
Centralized DOE ISFSI	85,000 – 120,000	600,000 – 750,000

Analysis

This report treats stored current inventories of spent fuel as belonging to one of three categories. These are:

Category 1) Spent fuel stored at an operating reactor ISFSI
Category 2) Spent fuel stored at an operating reactor site spent fuel pool
Category 3) Spent fuel stored at a shutdown reactor site

* Cost for moving spent fuel from the on-site spent fuel pool to the on-site ISFSI

These categories are selected due to varying differences in cost required to bring them to an at-reactor ISFSI versus a centralized ISFSI.

Category 1: Spent fuel stored at an operating reactor site ISFSI

The incremental cost of storing spent fuel in dry cask storage at an operating reactor site is relatively small, and largely independent of the amount of spent fuel being stored. Assuming an independent centralized ISFSI is already available, no cost savings due to operating cost would result unless all the spent fuel stored the at-reactor ISFSI is transferred to the centralized facility. However, the resulting cost saving of $600,000 – $750,000 per year is small compared to $85,000 – $120,000 per MTU needed to ship and re-cask already stored fuel. For a modest 5 years' worth of spent fuel, about 100 MTU, this is an upfront cost of $8,500,000 – $12,000,000, which even before considering a discount rate would take decades to recoup. In general, the economics of interim storage do not support the transfer of at-reactor spent fuel from an ISFSI to a centralized facility.

Category 2: Spent fuel stored at an operating reactor site spent fuel pool

Since many spent fuel pools have reached or will reach maximum capacity, spent fuel must eventually be moved from the pool to a dry storage facility. Assuming both an on-site ISFSI and centralized ISFSI are available, in general it would be less expensive to move spent fuel to the on-site ISFSI. Even though storage system costs for a centralized ISFSI are reduced due to economies of scale, this is offset by the significant cost of transporting spent fuel. However, this result is sensitive to the cost of transportation, so reactors with infrastructure compatible with cheaper transportation systems may find the use of centralized ISFSIs economically competitive.

Several additional situations exist in which use of a centralized ISFSI becomes preferable to use of an on-site ISFSI. First, since establishment of an at-reactor ISFSI requires approximately $8,000,000 – $12,000,000 in upfront costs,[33] a reactor without an existing ISFSI may choose to avoid this cost and subsequent operating costs by storing its spent fuel at another site. Since in this scenario transportation becomes a given, the improved storage economics of a centralized ISFSI make it the less expensive choice.

Second, a small number of situations exist in which a reactor site's dry storage capacity is constrained by space limitations or by state and local restrictions. For example, Minnesota established a nuclear waste law in 1994 that limits the amount of dry storage at the Prairie Island nuclear power plant.[34] More recently, Entergy, a nuclear utility, is experiencing difficulty creating an at-reactor ISFSI at its Vermont Yankee power plant due to strong local opposition.[35]

A reactor which loses access to spent-fuel storage risks premature shutdown, a prospect that can cost billions of dollars in lost electrical generation. While there is no past example of a reactor site being unable to obtain necessary dry storage capability, the consequences of such an occurrence are nevertheless great enough to warrant securing additional spent fuel storage options.

While a reactor with limited on-site storage could potentially send its spent fuel to another reactor site's ISFSI, this option is expensive and historically has only occurred between reactors owned by the same utility. A centralized ISFSI would be a more economical alternative and have greater reliability as an available alternative site. By acting as a nationally accessible option for interim storage, a centralized ISFSI reduces the likelihood of premature plant closures and increases interim storage flexibility, improving electrical generation security.

Category 3: Spent fuel stored at a shutdown reactor site

Fuel storage at shutdown reactor sites is significant because it incurs a far greater incremental storage cost than storage at an operating site or centralized ISFSI. This cost is greater because some of the equipment, electricity, and personnel needed during power generation at a reactor must be retained after shutdown to operate and maintain the ISFSI and spent fuel pool. Because spent fuel requires approximately five years of cooling in a spent fuel pool before it can be moved to dry storage, the first five years of increased operating cost shutdown are unavoidable.

After this five year period, the increased operating cost can be alleviated in one of two ways. First spent fuel in the spent fuel pool can be unloaded to the at-reactor ISFSI or a centralized ISFSI. This incurs costs similar to those associated with spent fuel in category two. Doing this would reduce the operating cost of a shutdown reactor by approximately $5,000,000 per year, to $3,000,000 – $4,000,000 per year. Second, spent fuel stored in the at-reactor ISFSI may be transferred to another ISFSI, eliminating operating expenses at the shutdown site entirely. Here, the situation is similar to that of spent fuel in category one, except here one can avoid the much larger incremental cost of continuing operations at a shutdown reactor. Therefore, while the upfront cost to transfer spent fuel remains similar, this cost can be recouped approximately five times more quickly, because the operating cost of an ISFSI at a shutdown site is five times greater.

Whether paying an upfront transfer cost to allay a high operating cost is economical depends on the period of interim storage expected at the shutdown site. This in turn depends directly on when a permanent geologic repository becomes available, because storage would presumably continue until the spent fuel is accepted for disposal. Specific decisions on whether to transport spent fuel to a centralized ISFSI depend on the quantity of spent fuel, exact costs, and predicted time until disposal. A rough calculation assuming 400 MTU of spent fuel at a shutdown site, corresponding to about a 20-year spent fuel inventory, and using the assumed cost values shows cost savings occurring within ten years of transferring the spent fuel to a centralized ISFSI, a timeframe similar to the opening of a permanent geologic repository. Therefore, it is likely that substantial cost savings can be realized in certain cases by moving spent fuel from shutdown reactor sites to a centralized ISFSI. These cost savings would on the order of the operating cost of storage at a shutdown site, tens of millions of dollars, and would therefore be sufficient to offset the costs of establishing and operating the centralized site.

In addition to providing cost savings, a centralized ISFSI can also reduce the economic uncertainty of interim storage. This uncertainty results from the uncertain date of repository availability, which means that interim storage costs must be paid for an unknown number of years. This uncertainty can become substantial considering the $8 – 9 million annual cost to store spent fuel at a shutdown reactor site. By transferring spent fuel to a centralized ISFSI at a known transportation and loading cost, a utility can exchange this high annual operating cost for the much lower incremental cost of storage at a centralized ISFSI, greatly reducing economic uncertainty. Assuming 400 MTU of spent fuel is stored at a shutdown site, transfer to a centralized interim storage site storing 20,000 MTU (half of PFS's 40,000 MTU capacity) reduces the annual maintenance cost of spent fuel from over $20,000 per MTU per year to less than $200 per MTU per year, a reduction of over 99%. Use of a centralized interim storage facility located at an existing DOE nuclear site can reduce this incremental annual cost still further.

It is worthwhile to note that spent fuel in categories one and two eventually becomes spent fuel in category three as reactors end operations and shut down. This provides an incentive to move spent fuel in a spent fuel pool at a reactor near shutdown to a centralized ISFSI. Five years after shutdown, spent fuel can be moved off the reactor site to allow for decommissioning, as described above. If this is predicted to be economical, additional savings can be realized by moving spent fuel from the fuel pool to a centralized ISFSI even before plant shutdown occurs. Doing this avoids paying twice for dry storage of the same fuel, first at an on-site ISFSI then again at the centralized ISFSI after shutdown. A centralized ISFSI can therefore also provide substantial cost savings to reactors expected to shutdown a certain period before repository availability. The length of this period, again, depends on the specifics of a site's spent fuel inventory and spent fuel export costs, but the same rough estimate as before shows it to be on the order of a decade.

Other economic considerations

There are several other important economic considerations not directly linked to spent fuel interim storage costs. First, removing spent fuel from a shutdown reactor site has benefits beyond avoiding an operating cost. Doing so also allows a reactor site to be permanently decommissioned, which makes a site's land available for other uses or sale. Second, implementation of a centralized ISFSI system requires the development of transportation infrastructure, including rail access at reactors, specialized railcars, and transport casks. It is likely that this transportation infrastructure can be reused to transport waste to a waste repository, resulting in a cost savings for permanent disposal.

Similarly, while use of a centralized ISFSI would result in a net increase in transportation, a centralized ISFSI located near a repository site could greatly reduce the transportation distance necessary for disposal once the repository becomes available. Therefore, the upfront cost associated with transportation to a centralized ISFSI can be offset by a transportation savings during disposal. This offset can be a substantial portion of the \$30,000 – \$55,000 cost assigned to upfront transportation, and can drive the total transportation and storage cost of using a centralized ISFSI below that of using an on-site ISFSI for a significant fraction of category two spent fuel. In this scenario, the use of a centralized ISFSI would lead to reductions in total system cost greatly beyond the savings outlined in the upfront cost analysis.

This conclusion is supported by the PFS economic analysis, which finds that total system cost decreases monotonically as more fuel is stored at the PFS facility rather than at-reactor ISFSIs.[36] This result is expected because of the close proximity of the Utah PFS site to the assumed Yucca Mountain repository site.

While this net decrease in system cost is a positive, utilities do not benefit from cost reductions realized during spent fuel disposal. This is because the cost to dispose of spent fuel is paid by the federal government's Nuclear Waste Fund.[37] Instead, utilities see only the upfront storage and transportation costs shown in Table 1, which puts centralized ISFSIs at an economic disadvantage. Subsidies for spent fuel transportation to centralized ISFSIs can make utilities' use of a centralized ISFSI economical in more situations, allowing total system cost reductions to be achieved.

Based on the above, it seems logical to try and eliminate disposal transportation costs completely by creating a centralized ISFSI at a likely disposal site, i.e. Yucca Mountain. In this scenario, total transportation costs would not increase with use of the centralized ISFSI, resulting in a minimized total system cost. However, policy factors have overridden economic considerations regarding such a siting decision; these factors are discussed in greater detail in the policy section of this report.

Finally, additional economic costs can be attributed to changes in the risk of accident or sabotage. These costs are difficult to forecast with certainty and are not included in this economic discussion, but are referenced later in the safety and security sections of this report.

Summary of economic factors

Centralized interim storage is economically advantageous largely due to economies of scale, which allow it to provide storage at lower cost than at-reactor ISFSIs. However, this savings is offset by the relatively large cost of transportation, and in some cases the need to purchase a replacement storage cask at the centralized site. Therefore, the decision to use centralized storage depends on the specifics of the spent fuel in question, and must be approached on a case-by-case basis.

In general, centralized interim storage allows for cost savings in situations where transportation of spent fuel is necessary, such as in the case of reactors without sufficient on-site interim storage capacity. Centralized storage also gives utilities an option to avoid paying excess ISFSI operating costs, especially the high costs associated with spent fuel pools at shutdown reactor sites. Though dependent on site specifics, operating cost savings in these situations are likely to exceed the cost of transferring spent fuel to a centralized ISFSI.

In general, it is economically unfavorable to transfer spent fuel at existing at-reactor ISFSIs to a centralized facility if the associated reactor is still operating and not close to shutdown. This means that a large-scale centralized storage system that consolidates existing dry-storage inventories of spent fuel would require considerable additional expense.

For spent fuel in a spent fuel pool, it is generally less expensive to transfer it to an on-site ISFSI than a centralized ISFSI, but this finding is sensitive to the cost of transportation to the centralized site. However, despite its higher upfront costs, use of a centralized ISFSI near a permanent repository site can reduce backend disposal costs and result in lower overall system costs.

A centralized storage facility can provide flexibility to the nation's interim storage infrastructure, improve the reliability of nuclear energy, and reduce economic uncertainty in spent fuel management. Centralized storage can also substantially reduce system cost, by removing spent fuel from shutdown or near-shutdown reactor sites, by potentially replacing at-reactor ISFSIs, and reducing the cost of spent fuel disposal.

As a centralized ISFSI, the proposed PFS facility will be able to produce the benefits outlined above. Its proposed capacity, 40,000 MTU, will be enough to accept all category three spent fuel and a significant fraction of category two spent fuel. From an economic viewpoint, the PFS facility is adequate for servicing the interim storage needs of the existing U. S. nuclear power reactor fleet.

Environmental and safety factors

Given the potentially hazardous nature of spent fuel, a responsible spent fuel management plan must aim to minimize detrimental environmental and human health effects. These effects can be attributed to three sources: site construction and decommissioning, transportation, and storage. In addition, the effects can be divided into three categories: non-radiological effects, radiological effects resulting from normal operation, and radiological effects resulting from potential accidents.

The single most useful source studying the health and environmental impacts of centralized interim storage is the Final Environmental Impact Statement (FEIS) for PFS issued by four federal agencies: the Nuclear Regulatory Commission, the Bureau of Indian Affairs, the Bureau of Land Management, and the Surface Transportation Board. The FEIS provides a comprehensive review of the impacts PFS would have on geology, water, air, ecology, and human health, and compares them to the impacts of four alternatives. The alternatives studied in the FEIS include alternative siting and infrastructure for the proposed PFS facility, as well as a "no-action" alternative that is applicable to the analysis in this report. The FEIS includes the impacts resulting from spent fuel transportation, and details both incident-free and potential accident impacts.

In this analysis of the environmental effects of centralized interim storage, it is assumed that the proposed PFS facility may be used as a representative model for similar sites. Because the PFS facility's environmental impact is not dependent on unique conditions of PFS's site location, similar centralized storage facilities at other locations are assumed to cause equivalent or reduced environmental effects.

General environmental impact

The FEIS generated for the PFS site details the expected environmental impact of the proposed site on a variety of different aspects of the environment. Its findings summarize the impact of PFS and the no-action alternative in a particular area as small, moderate, or large, defined by the study as follows:

- ***Small**. The environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource.*
- ***Moderate**. The environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.*
- ***Large**. The environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.*

The FEIS's findings for non-human health resources are reproduced in the Table 2, shown below. They include the cumulative impact resulting from construction and decommissioning, transportation, and storage over an expected 40 year operating lifetime. The FEIS proposes a number of measures designed to mitigate these impacts where possible, and suggests that they become requirements for the PFS facility. The contributions of these mitigation measures are therefore included in the findings. Where applicable, the FEIS report makes use of conservative estimates and assumptions, so the following impacts serve as an upper bound to what the actual impacts of PFS would be.

Table 2: Environmental impact of the PFS facility, as determined by the PFS FEIS

Potentially impacted resource or category	Impact of the proposed PFS site	Impact of at-reactor storage only
Geology, minerals, and soils	Small	Small
Water resources		
Surface water	Small	Small
Flooding	Small to moderate	Site-specific
Water use	Small	Small
Groundwater	Small	Small
Air quality	Small to moderate	Small
Ecological resources		
Vegetation	Small	Site-specific / small
Wildlife	Small	Site-specific / small
Wetlands	Small	Site-specific / small
Perennial and ephemeral streams	Small	Site-specific / small
Threatened and endangered species	Small	Site-specific / small
Socioeconomics and community resources		
Human population	Small	Small
Housing	Small	Small
Education	Small	Small
Utilities	Small	Small
Solid and sanitary waste	Small	Small
Traffic	Small to moderate	Small
Economic structure	Small to moderate (but beneficial)*	Small
Land use	Small to moderate	Small
Cultural resources	Small to moderate	Small
Noise	Small	Small
Scenic qualities	Moderate	Small
Recreation	Small	Small
Environmental justice	Small	Small

From the findings in the FEIS, it is apparent that the majority of impacts of PFS on its natural and societal environment will be small. Furthermore, none of the impacted categories under consideration suffer large or destabilizing impacts as a result of the PFS facility. The impact on air quality, one of only two moderate impacts, arises mainly as a result of dust from earth disturbance during construction, while greenhouse gas emissions during operation from the use of two locomotives, vehicles, and a generator are considered negligible. Ultimately, the construction, use, and decommissioning of the PFS facility will not result in any permanent adverse effects to the environment, and the differences in environmental impact between PFS and strictly at-reactor storage are minor.

The above conclusion may be extended to similar centralized storage systems utilizing intelligent site-selection and appropriate mitigation measures. While the proposed PFS facility will exclusively use rail for transportation of spent fuel to the facility, any combination of rail and truck shipments would constitute such a small fraction of the national total that resulting air quality and other environmental impacts from transportation will be small.

* This impact is large and beneficial for the Skull Valley Band of Goshute Indians.

Non-radiological human health impact

The FEIS for PFS concludes that non-radiological health impacts of PFS result from industrial accidents during facility construction and operation, transportation accidents, and latent health effects from transportation emissions. Each of these health risks is not unique to the PFS facility and is characteristic of many types of large-scale industrial operations.

Workforce construction and operation accidents

To estimate occupational fatalities and injuries resulting from construction and operation of PFS and its transportation infrastructure, the FEIS multiplied the peak workforce, the period of work, and the statistical probability of fatality or injury per period worked for each phase of facility construction and operation[*]. This procedure generates an expected value for worker injuries and fatalities over PFS's lifetime.

Using this procedure, the FEIS calculates that no fatal injuries and 92 nonfatal injuries are expected to occur for workers during the construction and operation of PFS. This estimate represents a conservative value because the actual workforce employed will be at times less than the peak workforce assumed by the FEIS. This number of workforce injuries over a 40-year operating period is judged to be small by the FEIS.

Other potential centralized storage facilities would involve similar construction and operation workforces and work requirements, so expected occupational injuries would be similar to those of the PFS site. Likewise, because the basic infrastructure and design of cask storage is the same at centralized and at-reactor sites, an expansion of dry-cask storage at reactor sites would have similar labor requirements. As a result, non-radiological occupational health impacts are both comparable and minor for centralized and at-reactor interim storage.

Transportation accidents

The FEIS computes fatalities and injuries due to rail transportation by multiplying a characteristic transportation distance by the number of shipments necessary to fill PFS, then multiplying this value by the expected accident risk per railcar-km. The distance used assumes shipment from an eastern reactor site to PFS and then back again, a conservative value. Likewise, the number of shipments is set to the maximum possible. Under this scenario, transportation accidents are estimated to cause 1.48 injuries and 0.78 fatalities over a 40 year period[†].

While the PFS FEIS does not consider the health impact of road transport accidents, analysis by the DOE in the Yucca Mountain repository FEIS suggests that road transportation by truck would result in approximately 60% more traffic accident fatalities than rail transport.[38]

[*] This statistical probability is drawn from historical records of fatalities and injury for industry projects
[†] These and other estimates for health impact in this report are statistically expected values, and correspond to the sum of the number of fatalities expected in a scenario weighted by the probability of the scenario. Due to their statistical nature, these estimates do not necessarily need to be whole-number values.

Emissions

A slight health impact results from vehicular emissions during transportation. Assuming the same number of railcar-km as for transportation accidents, and further assuming a uniform urban population density, the PFS FEIS estimates that 1.14 latent fatalities would result from train emissions. This is extremely low for a 40-year operation. Road transportation would result in a comparable health impact. In either case, the number of shipments needed would be a minor fraction of nationwide shipments.

Continued use of strictly at-reactor storage does not eliminate the need to transport spent fuel. Shipments will still need to be made between reactors, and spent fuel will ultimately need to be consolidated at a reprocessing or permanent disposal facility. Overall, while use of a centralized ISFSI would increase total transportation distance, the health impact from transportation accidents and emissions would be minimal.

Radiological impact of normal operations

Despite the heavy shielding that storage and transportation casks provide, a non-zero amount of radiation penetrates the shielding and exits into the environment. While the exact health effects of low-level radiation are not fully known, it is possible to conservatively estimate its health impact by extrapolating linearly from the known effects of higher doses and dose rates. This assumed linear relationship between dose and health impact is known as the linear no-threshold hypothesis. Using the linear no-threshold hypothesis, 1 rem of exposure is equivalent to $5*10^{-4}$ latent cancer fatalities, or LCF.[39] The LCF equivalent of a dose is the expected risk to an individual or group of a cancer fatality caused by a given dose of radiation. For example, an individual exposed to a dose of radiation equivalent to 0.001 LCF would have a 0.1% greater probability of developing a fatal cancer during his or her lifetime; a group of one thousand such individuals would receive a collective dose equivalent to 1 LCF and would be expected to have one additional cancer fatality over their lifetimes as a result. Fatalities resulting from such exposure do not actually occur until significantly after the exposure takes place. As a reference, the overall probability of an individual dying from cancer due to all sources is about 23%,[40] and natural background radiation in the United States results in a LCF equivalent of 0.015% per year per individual.[41]

Worker exposure during construction and storage

Using time/motion studies to compute the exposure to workers during different phases of PFS construction and operation, the PFS FEIS concludes that the average dose to a worker involved in spent fuel transfer at PFS to be within NRC regulatory limits, and equivalent to $2.2 * 10^{-3}$ LCF per year. Because PFS or another centralized ISFSI would accumulate more spent fuel than an at-reactor ISFSIs, the occupational dose would be greater at the centralized ISFSI due to work occurring near a greater number of spent fuel casks. Since this greater dose is nevertheless small, the difference in health impact is minimal.

Public exposure during storage

The PFS FEIS considers the doses that would be experienced by individuals at the PFS boundary and at the nearest residence to the PFS facility. In each situation it is assumed that the facility is stocked to capacity with spent fuel that is more radioactive than expected. From this, it is calculated that an individual spending 2000 hours a year (a normal working year) at the PFS site boundary would receive a dose equivalent to about $3*10^{-6}$ LCF per year, about 2% of the natural background dose. An individual living at the closest residence 2 miles away would receive a yearly dose equivalent to $2*10^{-8}$ LCF, or about 0.01% of natural background. These values are very small and well below the regulatory limit. A similar health impact would be encountered independent of whether spent fuel is stored at reactors or at a centralized ISFSI, provided that a sufficient boundary is maintained around the facility.

Transport

The PFS FEIS estimates radiological impact during transportation by assuming all 40,000 MTU of spent fuel is transported on a route from the Maine Yankee reactor site in Maine to the PFS facility in Utah. This conservatively caps the radiological dose that would be experienced by the public and train crew, because this chosen route both is longer and passes through more population than an average route. Using this assumption, the FEIS estimates a total dose equivalent of 0.0918 LCF to the public and 0.00976 LCF to the train crew over the entire period of operation, both extremely small values. Because centralized ISFSIs sited at other locations would not involve average transportation routes greater than the Maine-Utah route, this value may be considered conservative for rail transportation to any ISFSI. The Yucca Mountain FEIS suggests that road transportation would result in approximately three times more latent cancer fatalities than rail transportation, so centralized ISFSIs utilizing other means of transportation would result in similar health impacts as well.

Radiological impact of off-normal scenarios and accidents

Storage and operations

The PFS FEIS examines the potential radiological impact to workers and the public for a variety of potential off-normal and accident scenarios occurring during storage. These include both credible events, such as loss of electrical power, operator error, cask drops, cask tip-over, cask surface contamination, and blocked cask inlet ducts, as well as hypothesized non-credible events such as canister leakage and on-site explosions. The majority of these scenarios result in no additional exposure to radiation, and none of the scenarios considered result in doses to workers or the public greater than regulatory limits. Additionally, the effects of natural phenomena, including floods, high winds, tornados, earthquakes, fires, and lightning, are considered. Of these, none result in canister damage or the release of any radioactive material. The only event that may result in an increased dose to workers is a tornado that blows wind-borne debris into a cask and damages its shielding. Such an event would not result in doses beyond regulatory limits, and recovery would involve transferring the affected canister to an undamaged cask. In each of these scenarios, the safety of spent fuel storage can be attributed to the extremely robust design of storage casks.

Overall, because no credible off-normal scenarios during storage would result in significant doses to workers or the public, the radiological health impact of off-normal operations is considered small by the FEIS. Since this conclusion is dependent on cask properties rather than site location, it may be extended to both other centralized ISFSIs as well as at-reactor ISFSIs.

Transport

The PFS FEIS uses results from the 1987 Modal Study to determine the health impact of transportation accidents. This study considers six categories of accident severity leading to differing amounts of radiological release, and develops a probability for each category. Computer simulations are then applied for the FEIS to calculate the expected health impact of a given radiological release. Using the Maine-Yankee to PFS route as representative in addition to other conservative assumptions about accident severity, the FEIS reports that the expected radiological health impact to the public due to transportation accidents to be equivalent to 0.042 LCF over the entire PFS transportation campaign. This value represents an extremely low risk of radiological harm from transportation accidents, and is lower than the corresponding non-radiological health impact of transportation accidents. The Yucca Mountain FEIS corroborates this value for rail transportation and establishes a similar value for road transportation, meaning that both rail and road transportation carry very little risk[*] in terms of radiological release during an accident.

While the radiological health risk due to transportation accidents are extremely small, this risk stems from the remote possibility of radiological release, which may have significant consequences. To address this potential, the Yucca Mountain FEIS considers the consequences of a "maximum reasonably foreseeable accident scenario," in which a transportation cask is breached and exposed to a fully engulfing fire, causing a fraction of the spent fuel to be dispersed into the atmosphere. This accident is assumed to occur in an urban environment. In this type of scenario, which is estimated to have a frequency of approximately $3*10^{-7}$ per year, expected exposures to the public are equivalent to about 1 LCF for a truck cask or 5 LCF for a rail cask.

As these values show, the risk associated with transportation accidents involving spent fuel is very low. This low risk can be attributed largely to the robust construction of the transportation cask, which is designed, tested, and certified to withstand extreme forces and conditions.[42] A transportation cask consists of multiple layered metal shells that can weigh over 100 tons, which along with additional impact-limiting barriers provide substantial protection again even extreme transportation accidents. The spent fuel contained within is a hard ceramic solid, making dispersal beyond a localized area unlikely even in an accident scenario that breaches the cask.

The primary societal consequences of a potential accident would be psychological and monetary, as the expected human health impact is very low. The economic impact of a radiological accident is highly variable depending on the circumstances and surroundings of the accident, so an attempt to quantify this cost is not made.

Centralized interim storage results in an extremely small additional radiological risk due to transportation accidents. Like transportation cost, this transportation risk is offset by a reduction in transportation during spent fuel disposal.

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[*] "Risk," as used here, corresponds to the mathematical definition of risk as probability multiplied by consequences. Therefore, a very-low-probability event may dominate risk if the consequences are relatively high, as may a low consequence event with high probability.

Other accident possibilities

Other accidents unique to the choice of centralized storage site may need to be considered. For PFS, the possibility of an accidental military jet or cruise missile collision with a storage cask was brought before the Atomic Safety Licensing Board (ASLB) as a contention against PFS by the state of Utah. This was considered as a possibility because the Utah Test and Training Range, an Air Force facility, is located near the proposed PFS site. The ASLB ruled that such an accident constitutes a non-credible event, meaning it has a less than one in one million chance of occurring.[43]

Summary of environmental and safety factors

Interim storage at both at-reactor and centralized ISFSIs has a negligible impact on the environment. Differences in environmental impact between the two can be attributed solely to facility construction. Proper site selection can ensure that centralized interim storage results in no significant or permanent environmental harm.

Non-radiological effects of centralized interim storage result from construction accidents, transportation accidents, and vehicle emissions. These effects are not unique to centralized interim storage and result from any industrial project.

The radiological effects of interim storage are safe to workers and nearly negligible to the general public, even in the case of accidents. Centralized interim storage entails a very slight additional radiological risk resulting from increased spent fuel transportation. This risk, even including potential accidents, is less than the expected health impact of vehicle emissions. The difference between the human health impact of centralized interim storage and of at-reactor storage is slight, and in both cases this impact is extremely small.

Security factors

With the presence of any potentially dangerous material, it is important to anticipate the possibility of malicious attack or theft. Due to the deliberate nature of such security threats, one cannot reasonably assign them a probability and calculate an expected cost. Because these attacks often target human lives and aim to create terror, it is important to actively safeguard against the negative consequences of such an attack. Therefore, for interim spent fuel storage, spent fuel must be secured against malicious attack and its consequences at all times.

For radioactive materials such as spent fuel, security threats fall into two general categories: sabotage and theft. In the former, the intent is to damage shielding and potentially disperse radioactive material, therefore exposing the environment and population to radiation. The latter involves stealing the material for future use in a radiological dispersal device or "dirty bomb," or a potential nuclear device. In addition, each of these types of events may occur during storage, transportation, or fuel transfer. The security centralized interim storage provides against these types of threats is considered below.

Sabotage

At the storage site

Security of spent fuel at storage sites is accomplished through both active monitoring and defense by surveillance and guards, as well as passive engineered barriers including fences, vehicle barriers, and the storage casks themselves. Site security at an at-reactor or centralized ISFSI is subject to NRC oversight, ensuring safeguards, personnel, and procedures able to withstand a design basis threat (DBT).[44] The DBT is meant to represent a significant potential attack, and for nuclear facilities includes multiple well-trained and armed attackers with insider assistance, appropriate equipment including explosives, and a vehicle bomb. Because it must conform to the same standards and regulations, security at a centralized storage site would be able to offer similar protection as it currently does at at-reactor sites.

In addition to regulated external safeguards, a recent report by the National Academy of Sciences (NAS) on the security of spent fuel storage at reactors details a number of security benefits inherent to dry cask storage.[45] The report's findings are based largely on ongoing confidential work by a Sandia National Laboratory committee studying the response of fuel casks to different attacks, including attacks using aircraft as missiles and attacks involving high explosives. The report finds that no dry storage system is able provide complete protection from radioactive release. However, due to robust and heavy storage cask construction as well as the solid, inert nature of spent fuel, radioactive dispersal in a credible attack scenario would be small and localized. Significant weaponry and force would be required to successfully breach a storage cask, and even large breaches in a cask would result in only mechanical dispersion of some spent fuel into the immediate vicinity. This is because spent fuel tends to break apart into relatively large pieces rather than mobile small particles. Recovery from such an event, although potentially expensive, would be straightforward. These findings are not dependent on the specific cask design employed. Ultimately, acts of sabotage against spent fuel storage casks at an ISFSI are estimated not to pose a major risk to the public or environment.

Because centralized interim storage would employ similar security measures and dry cask systems as at-reactor storage, there is no substantial difference in spent fuel storage security between the two. Minor security differences may arise from different facility locations as well as the capacity of a facility to repair a damaged cask or canister. For example, the proposed PFS site in Utah may be less attractive as a target due to its distance from population centers. It would also be easier to protect due to the greater visibility of the surrounding desert landscape. PFS will lack the capacity to handle bare spent fuel, so an attack that successfully breaches a canister would incur a greater economic cost for recovery, since appropriate handling equipment would need to be brought from off-site. This latter difference is more of an economic risk than a security one, since health and environmental consequences would remain similar.

Finally, the amount of spent fuel stored at an ISFSI does not greatly affect its security risk. Even though a larger storage facility may be a more attractive target, the compartmentalized, individually protected nature of dry storage makes it extremely difficult for an attack to sufficiently damage more than one spent fuel container at a time. Larger facilities storing more spent fuel can be secured for a smaller incremental cost per unit of spent fuel, making it more cost effective to secure a few large sites than many small ones. Therefore, a single storage site containing the United States' entire dry-storage spent fuel inventory could have its security bolstered to tremendous levels at a comparably modest cost.

Transportation

The transportation of spent fuel presents unique security vulnerabilities and challenges. Differences in risk between storage and transportation are due to a reduced number of security personnel guarding transport, fewer engineered barriers during transport, and potential proximity of transportation routes to population centers. Each of these factors make spent fuel in transit a more appealing and accessible target to attackers, thus increasing risk. Nevertheless, the safety characteristics of transportation casks and spent fuel limit the potential consequences of an attack. While storage casks are designed to provide shielding and withstand accidents and natural events, transportation casks are further required to withstand the large forces and stresses possible during a transportation accident. Transportation casks consist of layered metal shells weighing up to 100 tons, which yield protection similar to that of an armored vehicle.[46] As a result, the security characteristics resulting from storage casks' robust construction apply equally to transportation casks. Again, the hard ceramic nature of spent fuel means that dispersal during transportation sabotage would be small and localized.

The PFS FEIS supports this conclusion, stating briefly that expected radiological release during sabotage of transportation would likely be small. However, the health consequences of even small releases may become significant in a heavily populated environment. This is considered in depth in the FEIS for the Yucca Mountain repository, which includes DOE computer analysis of maximum reasonably foreseeable sabotage scenarios for typical casks, representative spent fuel contents, and average weather conditions in an urban environment. This analysis concludes that road transportation sabotage would result in a maximum expected population-dose of 96,000 person-rem, equivalent to 48 LCF. The maximally exposed individual would experience a rise in lifetime fatal cancer risk from 23% to 29%. Rail transportation sabotage would result in a maximum expected population-dose of 17,000 person-rem or 9 LCF, with the maximally exposed individual's fatal cancer risk rising from 23% to 25%.

Compared to other potential attacks against non-radiological targets, the health impacts of spent fuel transportation sabotage are not remarkably large, especially considering that radiological health impacts occur significantly after exposure. Nevertheless, such acts of sabotage may result in enormous psychological and monetary costs. To address public concern and prevent unnecessary health risks, coordinated local, state, and federal emergency response plans are developed prior to any transportation of spent fuel. There is high confidence that such systems are capable of protecting the public to a high degree in the event of an accident or sabotage involving spent fuel transport.[47]

Because acts of sabotage are deliberate occurrences, the probability of spent fuel transportation sabotage does not increase proportionally with an increase in spent fuel transportation. Therefore, even though use of centralized interim storage requires increased spent fuel transportation, forgoing this increased transportation may not reduce sabotage risks, because sabotage can still occur during transportation to a disposal site. Sabotage risks will exist unless all shipments are performed at a time when sabotage is no longer a significant possibility.

During Transfer

Use of a centralized storage facility requires the transfer of arriving spent fuel from its transportation container to a storage cask, and the reverse process for departing spent fuel. These processes do not significantly increase sabotage risk for several reasons. First, they occur at the storage facility, meaning they are protected by the facility's active and engineered security measures. Second, spent fuel is always transferred in a manner that maintains cask-like shielding, and thus cask-like protection, at all times. This is accomplished either through direct linkage between the transport cask and a horizontal storage vault, or use of a transfer crane that lifts spent fuel canisters directly into and out of a transfer cask. Finally, because centralized facilities will be sited in remote locations, the public health impact of sabotage during transfer at a centralized site is likely to be minimal.

Other sabotage concerns

In addition to examining the security of spent fuel in dry cask storage, the NAS report also examines the safety of spent fuel being stored in spent fuel pools. The report finds that an attack against a spent fuel pool that partially or completely drains the pool may lead to a fire that releases a large quantity of radioactive material. The potentially catastrophic consequences of such an attack can be mitigated, the report recommends, by transferring all sufficiently cooled spent fuel from the pool to dry cask storage. Because centralized interim storage increases the quantity and accessibility of dry-cask storage, it may facilitate significant security improvements at spent fuel pools by allowing the NAS report's recommendation to be carried out more readily.

Theft

There are concerns that spent fuel may be stolen and used in a radiological dispersal device (RDD) or "dirty bomb," or used to create a nuclear weapon. However, a number of factors make spent fuel an unattractive target for theft.

First, spent fuel is not an ideal material for weapon making. Because it is a hard ceramic solid, spent fuel used in a basic RDD would likely break up into comparatively large pieces for which cleanup would be manageable. It is unlikely that the spent fuel could be aerosolized and impact an area beyond the initial explosion. The NAS report also notes that better RDD materials can be obtained at other facilities or even purchased.

Similarly, spent fuel cannot be used to create a nuclear weapon without access to sophisticated reprocessing technology and facilities. This requirement poses an enormous hurdle to nuclear weapons creation. Sizable amounts of spent fuel would be required which would not be allowed to go uncontrolled long enough for a weapon to be created.

Second, the properties of spent fuel and its casks make it extremely difficult to steal in any quantity. Spent fuel is extremely radioactive and physically hot; it cannot be handled directly. Opening a cask and removing spent fuel requires heavy specialized equipment. Theft of an entire cask from storage would require specialized transport equipment, as such casks can weigh in excess of 100 tons. Further, the security infrastructure guarding spent fuel from sabotage also provides effective protection against theft. The possibility of hijacking spent fuel while it is in transit exists, but multiple safeguards, including escorts, satellite tracking, and communication with emergency response, are designed to make such a scenario essentially impossible. Additional confidential safeguards and procedures exist which make it difficult for potential thieves to anticipate and defuse every countermeasure.

Summary of security factors

Overall, the security of spent fuel stored in dry casks is very high, due to regulated security measures and multiple barriers to access. Further, consequences of a successful attack are comparably minor; no credible attack scenario would result in widespread radiological harm or result in unmanageable recovery costs. There is no significant difference in risk between storage at a reactor ISFSI and a centralized ISFSI. However, a possible and slight security disadvantage of centralized storage results from risk of sabotage during spent fuel transportation. As noted, radiological effects would likely be minor in such a scenario, but economic and psychological effects may be large. The public health consequences of a maximally reasonably foreseeable attack scenario would be no greater than those of an equally determined attack on a non-radiological target. Finally, as spent fuel is both an unattractive and extremely difficult target for theft, the risk of theft is very slight for all interim storage arrangements.

Policy factors

Policy goals

An interim storage strategy must satisfy a number of goals to be successful. It must minimize safety and security risks to the public, minimize environmental impact, and be cost effective. Further, it must be capable of managing present and future inventories of spent fuel until a disposal option becomes available.

In addition to ensuring the achievement of these goals, public policy concerning interim storage must satisfy a number of policy goals as well. These policy goals include addressing public perceptions of risk, ensuring environmental justice, reducing economic uncertainty, and demonstrating a commitment to manage spent fuel. The federal government's interest in these different goals and steps it can take to realize them are discussed below.

Safety and security

The federal government must ensure the safety and security of spent fuel interim storage and transportation, in order to prevent potential public health impacts as well as maintain public confidence regarding nuclear energy.

Overall, there is little difference in the safety and security of different interim storage schemes, due to active security measures required at spent fuel storage facilities and the robust construction of spent fuel casks. Neither storage at at-reactor ISFSIs nor a centralized ISFSI entail significant risk to the public or the environment. However, since transportation of spent fuel introduces additional safety and security risks, moving spent fuel to a centralized ISFSI creates a slight increase in risk. Nevertheless, transportation of spent fuel will be necessary even without use of a centralized ISFSI, for both inter-reactor transfers and transfers to a permanent repository. Therefore, use of a centralized ISFSI only results in a fractional increase of an existing small risk. Meanwhile, centralized ISFSIs can significantly improve the security of spent fuel pools by allowing them to empty more of their contents.

Spent fuel transportation and its associated risks are a necessary but manageable part of any nuclear fuel cycle. The NRC, together with federal and state governments, has gone to great lengths to reduce both the probability and consequences of transportation incidents, and has made large advances in recent years to improve transportation security. As a result, the NRC has great confidence that even severe transportation incidents would not lead to large or wide-spread health impacts.

Differences in risk between different interim storage plans are insufficiently large to justify choosing a plan based on risk factors alone. National policy should continue to acknowledge spent fuel transportation risks and responsibly set and enforce measures limiting this risk.

Public perception of risk

Despite only small differences in safety and security between at-reactor and centralized ISFSIs, studies have shown that the public perceives federal management of spent fuel at a single site as being safer and more secure than private management at numerous sites. This perception is justified partly by the fact that spent fuel can be secured more easily if it is all located at a single site. This perception gives the government a slight incentive to take title of spent fuel and use centralized or consolidated storage.

On the other hand, there is strong public suspicion of and opposition to spent-fuel transportation. Historically, spent fuel shipments have been met with strong public resistance, and there has been significant opposition to policies requiring spent fuel shipment, including centralized interim storage and the Yucca Mountain repository.

While opposition to transportation is unlikely to completely prevent disposal or centralized interim storage plans from being carried out, it may become a significant impediment to such plans. It is in government's and industry's interest to address public perception of risk in order to alleviate public concern and facilitate spent fuel shipments. This has been done successfully in the past through a policy of open communication and public outreach.[48] Industry and government should establish an ongoing dialogue with potentially affected communities about the risks and precautions involved in spent fuel transportation. Essential state and local emergency responders should be trained and available well before the start of any transportation campaign in order to guarantee safety and allay public concerns. Any operation involving spent fuel transportation should be accompanied by a high degree of transparency and public access to pertinent information.

Environmental impact

Interim storage in any configuration has very little environmental impact, and most of this environmental impact is associated with the construction of new facilities. Proper siting of independent ISFSI facilities can insure that no significant damage to the environment results. Evaluation of environmental impact is already a licensing requirement for these facilities, so further policy action is not required.

Environmental justice

One criticism of the PFS proposal is that it unfairly burdens a minority group with the hazards of spent fuel. This criticism is unsupported, as the PFS FEIS determines that the proposed PFS facility results in no disproportionate hazard to any disadvantaged or minority group. The FEIS also states that the Skull Valley Band of Goshute Indians, which is hosting the PFS site, will see significant economic benefits from the proposed facility. Since environmental justice is an important concern, current policy to examine environmental justice issues during licensing should be continued.

Cost of interim storage

The federal government holds stake in the total system cost of interim storage. Due to its failure to begin accepting spent fuel in 1998, the government is potentially liable for the cost of interim storage, which could amount to billions of dollars. An effort to reduce this cost may therefore reduce future liability. In addition, a prior settlement with one utility has exempted the utility's payment into Nuclear Waste Fund, so interim storage expenses can come at the cost of permanent repository funding.[49]

Higher interim storage costs also result in higher nuclear electricity prices. If the federal government wishes to support continuing use of nuclear power, it can help maintain nuclear electricity's economic competitiveness by implementing policy that reduces the cost of interim storage. Doing so promotes energy diversity and energy security.

There are a number of actions that can be taken at the national level to reduce the cost of interim storage. First, given the U. S's large inventories of spent fuel and the advantages that canister-based systems provide, dry storage systems using dual-purpose canisters with single-purpose storage and transportation casks should be implemented at new storage facilities where possible. Canister manufacturing standards should be established by DOE and industry so that future spent fuel canisters can be used in a variety of storage, transportation, and handling systems. To address different infrastructure requirements and allow flexibility, separate standards should be established for small canisters for road transportation and large canisters for rail transportation. Such standards would simplify cask operations and make them safer, as well as reduce handling and transportation costs.

Because centralized interim storage leads to a reduction in system cost, government should either support private centralized sites or develop a federal site. Potential federal centralized storage sites should be developed at DOE facilities in order to take advantage of available infrastructure and reduce costs further.

One large expense of spent fuel storage and disposal is the cost of transporting spent fuel. These costs can be reduced by siting a centralized storage facility near a potential repository site, or, barring that, at a geographically central location. Cost savings realized in this manner benefit the federal government during spent fuel disposal, so use of centralized ISFSIs should be encouraged by using a portion of this future savings to partially subsidize transportation to the centralized ISFSI.

A policy that consolidates all current stores of dry-storage spent fuel would increase the cost of interim storage, because in most cases it is cheaper to continue using existing at-reactor ISFSIs. Spent fuel stored at these sites should remain there until permanent disposal becomes available.

In the long term, government should aim to optimize the interim storage infrastructure servicing future nuclear power plants. Such an infrastructure would involve one or a few centralized interim storage sites that would accept spent fuel from all future operating reactors, eliminating the need for at-reactor ISFSIs. These future reactors would use standardized spent fuel handling infrastructure and have uniform access to transportation, minimizing transportation cost and difficulty. The centralized site or sites would preferably be centrally located or near potential repository sites, to reduce disposal transportation costs. A completely centralized interim dry storage system can result in total system cost savings on the order of 30%, which for a long-term expansion of thirty new reactors can amount to billions of dollars.

Economic uncertainty

Centralized interim storage can be used to reduce the economic uncertainty of interim storage, by lowering the annual incremental cost of maintaining spent fuel. This reduction can be on the order of 99% for spent fuel stored at a shutdown reactor site.

By doing this, centralized interim storage makes the system cost of interim storage far less dependent on the date of repository availability, reducing the economic pressure to open a repository. It also prevents interim storage costs from becoming overwhelming as more reactors shut down. On the whole, a centralized ISFSI system would normalize the cost of interim storage, providing valuable economic and economic security benefits.

Adequate storage capacity

Most at-reactor ISFSIs can be expanded to store all of the spent fuel generated over the plant's lifetime. For reactors where this is not possible, access to interim storage must be made available, to ensure continued reactor operation. This can be done via inter-reactor transfers or use of a centralized storage facility. Of these, centralized storage would be a more economical and accessible alternative. Policy supporting centralized storage can guarantee the availability of sufficient interim storage for existing United States reactors. This in turn would improve the future reliability of nuclear power.

Demonstrating the government's commitment to manage spent fuel

The 1982 NWPA commits the government to development of a permanent geologic repository for the disposal of spent fuel. Delays in this project have shaken public and utility confidence in the government's ability and will to manage spent fuel. This lack of confidence in the government's commitment is likely to discourage future investment in nuclear energy.

To build public confidence, the government must first continue to focus attention and funds on the creation of a permanent geologic repository. A repository would the ideal next destination for much of currently existing spent fuel, and successfully opening one would conclusively demonstrate the government's ability to permanently manage spent fuel.

To encourage investment in new nuclear plants, the uncertainties utilities face regarding the potential cost and duration of interim storage must be removed. The federal government can remove this uncertainty by pledging to take title to and manage any spent fuel generated at a new nuclear facility. This can be done prior to the opening of a permanent repository through the creation of a federal centralized interim storage facility. Such a facility would allow for unhurried, measured implementation of future disposal or reprocessing plans.

Policy barriers

Although centralized interim storage can yield significant advantages in some of the policy areas outlined above, several policy barriers impede its implementation. By examining previous attempts to institute federal centralized interim storage, one can identify two primary barriers: interference with the Yucca Mountain Project and state opposition to hosting a centralized interim storage site. These barriers and what they entail for a national interim storage strategy are discussed below.

Interference with the Yucca Mountain Project

In the 1987 Nuclear Waste Policy Amendments Act, a provision was added to examine the idea of monitored retrievable storage (MRS) facility. An MRS facility would act as a centralized interim storage facility with additional spent fuel handling capabilities. Its intended purpose was to act as an early acceptance site for spent fuel, from which fuel could be recovered for disposal or reprocessing.

The MRS facility, as proposed in the act, was subject to a number of restrictions that linked it to the progress of a geologic repository. Construction of such a facility could not begin until a repository site was licensed, and the facility could not be situated in the same state as a candidate repository site. These restrictions on federal interim storage were created to ensure that federal interim storage would not delay creation of a permanent repository, and could not force a repository licensing decision by prematurely bringing spent fuel to the repository site. These concerns continue to shape interim storage policy today.

Since then, there have been a number of congressional attempts to create federal interim storage sites, including proposals to take title to spent fuel at reactor sites[50], to create a private storage facility at Yucca Mountain[51], and to simply require interim storage at Yucca Mountain[52]. Each attempt has failed due to concerns that federal interim storage would interfere in the Yucca Mountain Project by diverting repository resources, sapping political will, or improperly assuming that the Yucca Mountain site will be suitable for a repository.

The stated policy in the NWPA and past attempts to create federal interim storage demonstrate that a national interim storage policy must avoid interference with creation of a permanent repository. This can be accomplished by establishing three criteria for federal interim storage policies:

> Criterion 1: A federal interim storage facility should not be proposed at any candidate permanent repository site, including Yucca Mountain.

This criterion is similar to the 1987 NWPA MRS siting requirement, and prevents interim storage from directly impacting repository site licensing.

> Criterion 2: A federal interim storage policy must not reduce the funds available for disposal in a permanent geologic repository.

This criterion ensures that the full value of the Nuclear Waste Fund is applied towards permanent disposal. A separate interim storage development fund should be developed, which should ultimately be paid for by nuclear utilities. The NWPA originally intended that all interim storage costs would be paid by utilities; this should not change under federal management of interim storage. The Nuclear Waste Fund should only be applied to elements of interim storage that reduce the final cost of disposal, such as transportation to a centralized ISFSI.

Criterion 3: A federal interim storage facility should not be developed for existing inventories of spent fuel.

Taking title to existing inventories of spent fuel before disposal risks diminishing the political incentive to develop a permanent repository. To prevent this potential interference, the government should allow utilities to continue managing current stores of spent fuel, and take title to it only after a repository becomes available. Federal interim storage should only be created to better manage spent fuel generated at future nuclear reactors. Because the amount of spent fuel generated at current reactors will likely exceed Yucca Mountain's statutory capacity by 2010, taking title to spent fuel generated by future reactors will not diminish the need for a permanent repository.

A federal interim storage policy must meet these three criteria in order to avoid interfering with the creation of a permanent waste repository. Because repository creation will remain the primary goal of spent fuel management policy until a repository is opened, a viable interim storage policy cannot jeopardize or appear to jeopardize progress on a potential repository.

State opposition to hosting a centralized interim storage site

The most significant barrier facing any centralized interim storage plan is state and local opposition to hosting a centralized ISFSI. Attempts to establish an MRS in Tennessee in 1986 failed because of state opposition, and the MRS plan outlined in the 1987 NWPA never established a suitable site.[53] Likewise, Nevada highly opposes interim storage at Yucca Mountain, and Utah is highly opposed to the proposed PFS facility, although the fact it is planned on sovereign Goshute Indian land limits Utah's ability to influence the issue. Much of this opposition arises from the general public perception of spent fuel as being extremely dangerous.

There is no simple way to completely address public concerns or counter state opposition. It is likely that economic benefits would need to be offered to potentially affected communities or states in order to offset resistance to storing spent fuel. Ultimately, there is no guarantee that a suitable site can be found for federal centralized interim storage, or that such a site will not be prohibitively difficult or expensive to obtain. It is possible that the lack of an available site can, as it has in the past, halt plans to establish a federal centralized interim storage site.

This possibility can be addressed at an early stage and for relatively little expense by investigating potential candidate sites and determining if any are amenable to hosting spent fuel. Ideally, a state or community that can benefit from a spent fuel storage contract would volunteer to host a centralized ISFSI. This is basically what the Skull Valley band of Goshute Indians did for PFS. If no volunteers step forward, an effort to contact different states and negotiate a suitable storage agreement would need to be made. Additional methods of finding a volunteer host may be applicable as well, but these are largely beyond the scope of this report.[*]

[*] For example, consider Herbert Inhaber, "Can an Economic Approach Solve the High-Level Nuclear Waste Problem?" 1991, *RISK: Health, Safety & Environment*, Risk Assessment and Policy Association, vol 2. p 341.

Summary of policy factors

The policy goals and barriers of interim storage suggest a two stage national interim storage strategy, with a near-term stage dealing with storage of spent fuel generated at current reactors and a long-term stage concerning storage of spent fuel generated at future reactors.

In the near term, it is unlikely that the federal government will be able to establish federal interim storage or take title to existing spent fuel. This is due to legislative resistance to allow anything that may interfere with the Yucca Mountain repository project. Instead, government should allow utilities to continue managing the interim storage of existing spent fuel. It can do this while realizing the near-term policy benefits of interim storage by supporting the proposed PFS facility. These benefits include reduced system cost, reduced economic uncertainty, and assured access to dry storage capacity.

Support for the PFS facility can come in several forms. First, government can side with PFS in addressing challenges to its construction and operation. Next, government can facilitate transportation to PFS by training and situating state and local emergency responders before transportation occurs. At the same time, the nuclear energy industry can perform outreach services to address public concerns regarding spent fuel shipments. Finally, government can encourage use of the PFS facility by partially subsidizing the cost of transporting spent fuel to the facility. As discussed previously, the cost of such subsidies can be offset by future transportation savings during the disposal of spent fuel.

In the long term, the federal government should attempt to establish an optimized interim storage system. Such a system would involve one or a few federal centralized interim storage facilities, capable of managing the dry storage requirements of all future nuclear reactors and eliminating the need for at reactors ISFSIs. Handling infrastructure and transportation access would be standardized to facilitate transportation. With such a system, the federal government would be able to automatically take title of any spent fuel leaving a spent fuel pool, removing a major source of uncertainty for future investment in nuclear power. The cost of this optimized system should be borne by nuclear utilities as a fixed fee per quantity of spent fuel accepted. Such a fee will not result in higher nuclear electricity prices because the minimized system cost of centralized storage means utilities would have to pay more to store spent fuel at an on-site ISFSI.

Near-term action can be taken toward the long term goal of an optimized interim storage system. First, government should work with industry to develop universal standards for future spent fuel canister systems, building upon successful existing designs where possible. Second, and more important, the government should begin work to secure suitable sites for federal centralized interim storage. Establishing such sites is crucial to creating an optimized interim storage infrastructure, and must be accomplished before the government can pledge to accept all subsequently generated spent fuel.

Findings, Recommendations, and Conclusion

Findings

General findings regarding interim storage

Finding 1: Interim storage of spent nuclear fuel is a necessary part of the nuclear fuel cycle.
Because permanent disposal systems take a long time to develop and license, interim storage is necessary to guarantee the safety and security of spent fuel before disposal systems become available. Interim storage should therefore be optimized to be as safe, secure, and cost effective as possible.

Finding 2: Interim dry cask storage is safe and secure.
Interim storage at both at-reactor ISFSIs and centralized ISFSIs carries extremely low safety and security risks. The impacts of interim storage on the environment and on human health are extremely minor, even in the case of accidents or natural disasters. Spent fuel in dry casks is highly secure, and is an unattractive target for theft or sabotage. It is extremely unlikely that a successful attack would result in widespread release of radioactive material. The NRC has stated that dry cask storage can remain safe for periods of at least one hundred years.

General findings regarding spent fuel transportation

Finding 3: Spent fuel transportation is a necessary part of the nuclear fuel cycle.
Ultimate disposal of spent nuclear fuel requires transportation of spent fuel to a geologic repository. This is true regardless of the interim storage plan in use.

Finding 4: Spent fuel transportation entails a slight, albeit manageable risk.
Spent fuel transportation increases the probability and consequences of an accident or act of sabotage. These risks have been managed to the point that expected public health consequences due to spent fuel transportation incidents are extremely low.

General findings regarding centralized interim storage

Finding 5: Centralized interim storage involves no significant differences in safety and security compared to at-reactor storage.
Interim storage at ISFSIs is safe and secure regardless of whether it is located centrally or at reactor sites. Use of centralized storage results in a fractional increase in spent fuel transportation risk, which is slight and manageable. Properly sited, centralized interim storage has negligible environmental impact.

Finding 6: Centralized interim storage can lower the system cost of interim storage.
Economies of scale allow centralized ISFSIs to package and store waste at a lower cost than at-reactor ISFSIs. In many cases, this savings can offset the increased transportation cost of using a centralized ISFSI. Large savings can result by moving spent fuel away from shutdown or near shutdown reactor sites. Use of a centralized ISFSI reduces the future cost of permanent disposal by establishing transportation infrastructure and reducing the average distance to a

repository. These savings total more than the costs of constructing and decommissioning a centralized ISFSI, resulting in a lower system cost. Transportation improvements can substantially increase this benefit.

Finding 7: Centralized interim storage improves energy security and reduces economic uncertainty in spent fuel management.
A centralized ISFSI would guarantee access to cost-effective interim storage, thus safeguarding reactors against early shutdown and improving energy security. Centralized storage allows for the exchange of high shutdown-site-ISFSI operating costs for much lower centralized-ISFSI storage costs and a known transfer cost. This reduces the uncertainty faced by utilities regarding the cost of interim storage. This reduction in economic uncertainty similarly extends to currently operating and future nuclear power plants.

Policy findings

Finding 8: Near-term siting of a centralized interim storage site at Yucca Mountain is unlikely.
Siting a centralized interim storage at Yucca Mountain faces intense opposition from the state of Nevada, as well as the criticism that such a site prejudges the suitability of Yucca Mountain as a waste repository. There have been numerous attempts in the past to institute interim storage at Yucca Mountain, all of which have failed due to their potential to interfere with the repository project.

Finding 9: Of centralized interim storage proposals, the PFS proposal is closest to becoming operational.
PFS is in the last phase of an eight-year licensing process. No other centralized interim storage proposal has advanced that far in the licensing process.

Finding 10: PFS satisfies the call for near-term centralized interim storage.
The proposed PFS facility will be able to provide the near-term benefits of centralized interim storage outlined in this report. Its capacity and licensing period are sufficient to service the existing fleet of nuclear reactors.

Recommendations

Short-term recommendations

Recommendation 1: DOE should work with industry to develop canister standards and spent fuel handling infrastructure standards to be applied to new facilities and future nuclear power plants.
The institution of canister and infrastructure standards will make future spent fuel transportation and storage easier and cheaper. A standardized canister design allows for interoperability among handling infrastructure and cask systems at different reactors and ISFSIs, and facilitate facility and transportation licensing. These standards should be developed with

industry input, building upon currently successful designs where possible. Costs for developing these standards can be incorporated into the final cost of canisters and equipment.

Recommendation 2: The federal government should acknowledge spent fuel transportation risk as a small, necessary, and manageable risk, and facilitate spent fuel transportation.

Because spent fuel transportation is necessary, government should acknowledge its risks and pursue a policy of risk management rather than risk avoidance. In anticipation of future spent fuel transportation campaigns, it is important to facilitate transportation and address public perceptions of risk by preparing local and state emergency response personnel. The nuclear energy industry can also help facilitate transportation by performing outreach to communities and maintaining an open dialogue regarding the risks of spent fuel transportation.

Recommendation 3: The federal government should not consolidate spent fuel currently in at-reactor dry storage.

Consolidating all existing spent fuel at a centralized facility will increase the system cost of interim storage and provide little, if any, security or safety benefits. Doing so may address public perception of interim storage risk but can create further concern regarding spent fuel transportation.

Recommendation 4: The federal government should support the PFS proposal in lieu of establishing a near-term federal centralized interim storage facility.

It is unlikely that a federal centralized interim storage facility can be created within the completion timeframe of the PFS proposal. Apart from creating a storage site at Yucca Mountain, there is little the government can do to improve upon the benefits offered by the proposed PFS facility. Siting of a federal centralized interim storage facility at Yucca Mountain is very unlikely to occur in the near term because of state opposition and the potential for interference with the repository project.

The proposed PFS facility can provide near-term centralized interim storage benefits to all existing reactors. These benefits are reduced system cost, guaranteed accessibility to interim storage, and reduced interim storage economic uncertainty. A concurrent federal or private facility would be largely redundant. PFS can establish the groundwork for future centralized interim storage, and allows the government to continue focusing on a geologic repository.

Recommendation 5: The federal government should subsidize a portion of the cost to transport spent fuel to the PFS facility.

Shipments to PFS that bring spent fuel closer to Yucca Mountain will likely reduce transportation costs during disposal. PFS will also establish transportation infrastructure that can likely be reused for disposal. These reductions in disposal cost are part of the system cost reduction that centralized storage can provide. In order to realize these disposal cost savings, the federal government must share them with utilities by partly subsidizing spent-fuel transportation that leads to these savings. Financial assistance can also be offered in the form of funding for transportation infrastructure development. These economic aids can make centralized interim storage economically competitive with on-site storage for some reactors. Further, these aids may be paid using the Nuclear Waste Fund, since they should be offset by an ultimate reduction in disposal cost. Use of centralized interim storage brings spent fuel one step closer to disposal.

Long-term recommendations

Recommendation 6: The federal government should establish a long term interim storage strategy.

Interim storage is a necessary part of the nuclear fuel cycle, and it influences the safety, security, and reliability of nuclear power. Utilities, under federal regulation, are able to properly address safety and security concerns, but government involvement is necessary to optimize long term system costs and create a universal system for spent fuel handling. An interim storage strategy utilizing federal interim storage demonstrates the government's commitment to assume responsibility for spent fuel. Details of a recommended strategy are detailed in the following recommendations.

Recommendation 7: In the long term, the federal government should establish one or few federal centralized interim storage sites to serve the storage needs of future nuclear power plants.

Significant capital has been invested in current interim storage infrastructure, so only modest improvement of existing interim storage is possible. Current infrastructure, together with PFS, will be suitable for managing spent fuel generated at existing reactors. For future nuclear reactors, optimization of interim storage in the areas of cost and accessibility can be achieved by creating one or few centralized interim storage facilities. Using standardized spent fuel handling systems, such facilities can accept spent fuel from all future reactors, eliminating the need for separate at-reactor ISFSIs. A national-scale interim storage system will result in substantial interim storage cost savings and facilitate implementation of future disposal or reprocessing plans. It will provide ample time for careful consideration of spent fuel disposal and reprocessing options and allow for the development of favorable technological, political, and economic conditions. Therefore, such a site does not need to be, and should not be, linked to the prior opening of a geologic repository. A centralized interim storage site may also become an ideal location for reprocessing facilities, if reprocessing becomes a favorable option in the future.

Recommendation 8: The federal government should begin seeking candidate sites for future long-term centralized interim storage.

The greatest challenge for the implementation of centralized storage is finding a location at which to site the storage facility. This difficulty arises primarily as a result of regional opposition to spent fuel storage, and overcoming it may require providing economic incentives to the affected communities. The siting barrier can be encountered at an early stage and for relatively little cost, so investigations into potential sites should begin as early as possible. A fund similar to those appropriated for interim storage as the Spent Fuel Initiative in a recent House Energy and Water appropriations bill (H.R. 2419) would be ideally suited for this purpose.[54]

Sites proposed in the corresponding bill report (H. Rept. 109-86) for a federal storage facility include DOE nuclear facilities, other federal sites, closed military bases, and private interim storage sites including PFS. Candidate sites should be geographically central or close to potential repository sites, to minimize system costs. Sites adjacent to existing or decommissioned nuclear power plants may be considered as well.

Recommendation 9: Upon securing a site, the federal government should guarantee acceptance of all spent fuel generated at new nuclear reactors

Guaranteeing federal management of spent fuel eliminates one of the major uncertainties associated with future nuclear power plant operation. This guarantee can be contingent on a requirement that reactors use standardized spent fuel canisters and infrastructure and have adequate access to transportation routes. A long-term federal site may also accept spent fuel from currently existing reactors or shutdown sites as needed.

Recommendation 10: The costs of a long-term centralized interim storage site should ultimately be paid for by utilities.

Because interim storage, like disposal, is a necessary part of the nuclear fuel cycle, its cost should be reflected in the cost of nuclear electricity. Centralizing interim storage will reduce system costs, so this fee will be less than the cost utilities would pay for at-reactor interim storage. Even if utilities bear the cost, nuclear electricity costs will be reduced if centralized interim storage is instituted.

Conclusion

Current interim storage infrastructure was originally developed to meet immediate needs for interim storage, and based on premature assumptions about the availability of reprocessing and disposal facilities. While this current model of strictly at-reactor storage is simple and generally effective, significant benefits can be gained through the use of centralized interim storage. These benefits are primarily economic, and include reductions in system cost, greatly reduced economic uncertainty, and insurance against premature plant closure. The federal government in particular has a great deal to gain from centralized interim storage, as a federal centralized site could yield the above benefits while allowing the government to take title to and manage spent nuclear fuel.

Because interim storage will continue to be necessary as new nuclear reactors are licensed, an effort should be made to optimize future interim storage through careful planning and policymaking, instead of allowing immediate need to dictate policy as it has in the past. As discussed in this report, such an optimized system would be based on one or a few centralized interim storage facilities that replace at-reactor dry storage, and utilize standardized equipment and transportation infrastructure. The federal government plays a critical role in the development and implementation of such a system.

In the near term, instituting a fully-centralized system to service existing reactors and consolidate all dry-storage spent fuel is impractical due to both policy barriers and the significant investment in existing interim storage infrastructure. However, a private centralized interim storage facility can supplement existing at-reactor interim storage and provide short-term interim storage benefits while avoiding some of the policy barriers that restrict federal interim storage. Therefore, a national interim storage strategy should involve supporting private interim storage to service existing reactors in the near term, followed by the development of a fully-centralized federal interim storage infrastructure to service future reactors in the long term. By adopting a strategy that addresses both the short-term and the long-term need for interim storage, the federal government can ensure that interim storage best serves its purpose: to safely, securely, and cost effectively store spent fuel so that the best permanent disposal options can be implemented.

Citations:

[1] Nuclear Energy Institute, Fact Sheet, "High Level Waste: Used Nuclear Fuel," 2000. Available online http://www.nei.org/index.asp?catnum=2&catid=62

[2] Nuclear Regulatory Commission Fact Sheets, "Backgrounder on Radioactive Waste", 2005. Available online: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/radwaste.html/. The period of radioactivity can be considered to be on the order of 10 half-lives, which for plutonium-239 corresponds to 240,000 years.

[3] "Nuclear Waste Policy Act of 1982" (Public Law 97-425; 96 Stat. 2201)

[4] "Nuclear Waste Policy Act of 1982, as amended." (PL 97-425, 7 Jan. 1983 as amended by P.L. 100-203, Title V, Subtitle A (December 22, 1987), P.L. 100-507 (October 18, 1988), and P.L. 102-486 (The Energy Policy Act of 1992, October 24, 1992).). United States Statutes at Large 96 (1982): 2201

[5] Congressional Research Service, IB92059, "Civilian Nuclear Waste Disposal," 2001

[6] Nuclear Energy Institute, Nuclear Energy Overview "DOE Delays Yucca Mountain Opening Until 2012", February 14, 2005

[7] Nuclear Energy Institute, Fact Sheet "Status of Used Nuclear Fuel Storage," 2001

[8] Department of Energy, capacity based on capacities provided in 2002 RW-859 forms.

[9] Congressional Research Service, Mark Holt, 96-212 ENR, "Civilian Nuclear Spent Fuel Temporary Storage Options," 1998

[10] Nuclear Energy Institute, Fact Sheet "Status of Used Nuclear Fuel Storage," 2001

[11] Office of Civilian Radioactive Waste Management, Fact sheet, "Spent Fuel Pools." Available online: http://www.ocrwm.doe.gov/ymp/about/pools.shtml

[12] Paul M. Golan, presentation at DOE, "Office of Civilian Radioacive Waste Management Program Overview," July 2005

[13] see Nuclear Regulatory Commission regulations, Title 10, Chapter I, Part 72, *Code of Federal Regulations*, "Licensing requirements for the independent storage of spent nuclear fuel, high-level radioactive waste, and reactor-related greater than class C waste"

[14] For example, see Private Fuel Storage's proposed benefits, available online: http://privatefuelstorage.com/benefit/benefit.html

[15] For example, see Public Citizen criticism of Private Fuel Storage, available online: http://www.citizen.org/cmep/energy_enviro_nuclear/nuclear_waste/hi-level/fuel/articles.cfm?ID=10370

[16] Most recently, see House Report 109-086 - ENERGY AND WATER DEVELOPMENT APPROPRIATIONS BILL, 2006

[17] For example, see Rogers, Kenneth A.; Kingsley, Marvin "The Transportation of Highly Radioactive Waste: Implications for Homeland Security," Journal of Homeland Security and Emergency Management, Vol. 1, Issue 2, Article 13, 2004

[18] Public information about Private Fuel Storage is available at the PFS website, available online: http://privatefuelstorage.com

[19] For example, see physical characteristics of the Holtec International HI-STORM 100 storage cask, available online: http://www.holtecinternational.com/hstorm100.html

[20] For example, see physical characteristics of the Transnuclear Inc. TN 68 dual-purpose cask, available online: http://www.transnuclear.com/metalcask-tn68.htm

[21] International Atomic Energy Agency, IAEA-TECDOC-1192, "Multi-purpose container technologies for spent fuel management," 1990

[22] International Atomic Energy Agency, IAEA-TECDOC-1192, "Multi-purpose container technologies for spent fuel management," 1990

[23] See dry cask system use: Nuclear Regulatory Commission, Backgrounder "Backgrounder on Dry Cask Storage of Spent Nuclear Fuel," 2004

[24] Nuclear Regulatory Commission, Final Environmental Impact Statement for the Construction and Operation of an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, Utah (NUREG-1714, Vol. 1), 2001

[25] NRC, FEIS for PFS ISFSI, 2001, op. cit. see economic impact in chapter 8 for economies of scale multiplier

[26] Department of Energy, "Report to Update Total System Life Cycle Cost Estimate for Site Recommendation/ License Application," December 1999

[27] Department of Energy, TRW Environmental Safety Systems Inc, "CRWMS Modular Design/Construction and Operation Options Report," , December 1998,

[28] See largest rail container cost, NRC, FEIS for PFS ISFSI, 2001, op. cit.

[29] NRC, FEIS for PFS ISFSI, 2001, op. cit.

[30] Department of Energy, TRW Environmental Safety Systems Inc, "CRWMS Modular Design/Construction and Operation Options Report," , December 1998,

[31] Supko, Eileen M. "Minimizing Risks Associated with Post-Shutdown Spent Fuel Storage and LLW Disposal," 1998

[32] NRC, FEIS for PFS ISFSI, 2001, op. cit.

[33] Supko, "Minimizing Risks," 1998 op. cit.

[34] Laws of Minnesota 1994, chapter 641

[35] For example, see Vermont Yankee News, available online: http://www.nuclear.com/n-plants/Vermont_Yankee/Vermont_Yankee_news.html

[36] NRC, FEIS for PFS ISFSI, 2001, op. cit.

[37] 1982 NWPA, op.cit.

[38] Department of Energy Report EIS-0250, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," February 2002

[39] From value used in NRC, FEIS for PFS ISFSI, 2001, op. cit.

[40] From DOE Yucca Mountain Repository FEIS, 2002, op. cit.

[41] From values used in NRC, FEIS for PFS ISFSI, 2001, op. cit.

[42] see Nuclear Regulatory Commission regulations, Title 10, Chapter I, Part 71, *Code of Federal Regulations*, "Packaging and Transport of Radioactive Material"

[43] Private Fuel Storage News Release, "Atomic Safety and Licensing Board Recommends License for Spent Nuclear Fuel Site," February 24, 2005

[44] The design basis threat for nuclear facilities is described at: Nuclear Regulatory Commission regulations, Title 10, Chapter I, Part 73, *Code of Federal Regulations*, "Physical Protection of Plants and Materials," Section 1 "Purpose and Scope" Specific details of the DBT are classified.

[45] Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, National Research Counsel of the National Academies, "Safety and Security of Commercial Spent Nuclear Fuel Storage, Public Report" Washington, DC, 2005

[46] See transportation sabotage in DOE Yucca Mountain Repository FEIS, 2002, op. cit.

[47] See requirements at Nuclear Regulatory Commission regulations, Title 10, Chapter I, Part 73, *Code of Federal Regulations*, "Physical Protection of Plants and Materials,"

[48] For example, see Nuclear Energy Institute, "Nuclear Policy Outlook," second quarter 2004

[49] Congressional Research Service, IB92059, "Civilian Nuclear Waste Disposal," 2001

[50] See H.R.45 "To amend the Nuclear Waste Policy Act of 1982." 1999, and House Report 106-155 - "NUCLEAR WASTE POLICY ACT OF 1999," 1999, as well as S.1287 "An original bill to provide for the storage of spent nuclear fuel pending completion of the nuclear waste repository, and for other purposes." 1999, and Senate Report 106-098 – "NUCLEAR WASTE POLICY AMENDMENTS ACT OF 1999," 1999

[51] See S. 1478 "Private Interim Storage Facility Authorizing Act of 1995," 1995

[52] See H.R. 1270 "Nuclear Waste Policy Act of 1997," 1997, and House Report 105-290 – "NUCLEAR WASTE POLICY ACT OF 1997," 1997 as well as S. 104 "Nuclear Waste Policy Act of 1997," 1997, and Senate Report 105-010 – "NUCLEAR WASTE POLICY ACT OF 1997," 1997

[53] Congressional Research Service, Mark Holt, 96-212 ENR, "Civilian Nuclear Spent Fuel Temporary Storage Options," 1998

[54] See H.R. 2419 "Making appropriations for Science, the Departments of State, Justice, and Commerce, and related agencies for the fiscal year ending September 30, 2006, and for other purposes." 2005, and House Report 109-118 – "SCIENCE, STATE, JUSTICE, COMMERCE, AND RELATED AGENCIES APPROPRIATIONS BILL, FISCAL YEAR 2006," 2005

Additional References:

Nuclear Regulatory Commission NUREG-1350, Volume 16, Rev. 1, "Information Digest: 2004-2005 Edition," 2004

Domenici, Pete, *A Brighter Tomorrow: Fulfilling the Promise of Nuclear Energy,* Rowman & Littlefield Publishing Group, Inc., Lanham, Maryland, 2004

Smith, Jennifer A.D.; Reed, James B., *Spent Fuel Transportation: History, Status and State Involvement*, for the National Conference of State Legislatures, 2004

Bunn, Matthew, et al. "Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management," A Joint Report from the Harvard University Project on Managing the Atom and the University of Tokyo Project on Sociotechnics of Nuclear Energy, June, 2001

Skull Valley Band of Goshutes, *Skull Valley Goshutes*, (2005). Available WWW: http:// skullvalleygoshutes.org/

Congressional Research Service, Mark Holt, 97-403 ENR, "Transportation of Spent Nuclear Fuel," 1998