Nuclear Fuel Cycle Technology and Policy Program

Key Issues Associated with Interim Storage of Used Nuclear Fuel

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EXECUTIVE SUMMARY

The Issues

The issue of interim storage of used (spent)[1] fuel is dependent on a number of key factors, some of which are not known at this time but are the subject of this study. The first is whether or not the Yucca Mountain Project continues or is cancelled such that it may be able to receive spent fuel from existing and decommissioned nuclear power stations. The second is whether the United States will pursue a policy of reprocessing and recycling nuclear fuel. The reprocessing and recycling option includes recycling spent fuel into a mixed oxide fuel for light water reactors or in fast reactors that can transmute (burn) actinide wastes or even breed fuel for long term sustainability of nuclear energy to address potential uranium supply shortages, or all of the above. The reprocessing option can also be used as part of the waste management strategy to reduce the volume of high-level waste to be disposed. The third is the time it will take to site one or several interim storage sites given past unsuccessful efforts. The fourth is the political implication of allowing used fuel to accumulate at existing nuclear plant sites as it affects their continued operation and the construction of new nuclear plants presently being considered. Fifth, the length of time wet or dry cask storage is technically supported with the ultimate need to ship spent fuel to a disposal, reprocessing or storage site in the future without damage. Last, but not least, is the cost and challenges associated with the shipment of spent fuel from reactor sites to interim storage facilities and to the final disposal site as compared to leaving the spent fuel at existing reactor sites until such time as the policy decisions are made.

Nuclear utilities are anxious to have the spent fuel removed their sites, especially from those sites where the reactors are decommissioned leaving only the spent fuel. Complicating this issue further is the issue of utility lawsuits for breach of contract when the Department of Energy did not begin accepting spent fuel from nuclear sites in 1998. It is estimated that this liability to the US taxpayer could reach $11 Billion.

The purpose of this study is to examine these key aspects of interim spent fuel storage in more detail.

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[1]The term “spent” is currently being used to describe that fuel which is no longer useful in terms of reprocessing for recycling, while “used” is being used to describe which is still possibly useful for recycling. In this report, however, both terms will be used interchangeably without such a distinction.

Conclusions

The most significant finding is that regardless of the future of Yucca Mountain or a policy decision on the future of recycling, storage of spent nuclear fuel at reactor sites will continue for at least 15 to 20 years. This finding is based on the timing of a final decision on Yucca Mountain as determined by the Nuclear Regulatory Commission or Congress, the timing of making a national decision on recycling and its subsequent implementation, and the timing associated with finding a site, licensing and constructing an interim storage facility. Deciding to build an interim storage facility until these fundamental issues are resolved does not make economic or policy sense. The only policy decision that merits consideration is the development of a small interim storage site for decommissioned nuclear plants where the only remaining facility is the spent fuel stored on concrete pads. *This finding leads to the conclusion that interim storage of spent nuclear fuel must be an integral part of any national waste management strategy.*

The siting of a centralized regional interim storage facility will be more difficult than in the past due to a lack of a clear exit strategy for the spent fuel in storage. Past volunteer efforts authorized by Congress with the creation of the Nuclear Waste Negotiator to site a Monitored Retrievable Storage facility failed due in part to political opposition and congressional political interference in the process once decisions were near. There are no indications that there are any fundamental changes either in the politics of siting interim facilities or the willingness of states and local communities to accept such a facility. Some suggest that co-locating a reprocessing plant and an interim storage facility with its attractiveness of jobs and economic stimulus might be a differentiator today, but that remains to be seen.

The Nuclear Waste Policy Act, as Amended in 1987, severely restricts the Department of Energy from building an interim waste storage facility until Yucca Mountain obtains an operating license. This legislative restriction needs to be removed to allow the construction of such a facility independent of the progress on a repository site. Of course, this will make the siting of an “interim” facility more difficult. Private utility efforts at building a regional interim storage facility such as the Private Fuel Storage (PFS) project have also been stymied by national and state political opposition despite being granted a Nuclear Regulatory Commission license to build and operate such a facility after a 10-year licensing process.

Even if a volunteer site could be found, the licensing process could last 10 years with another 3 to 5 years for construction before spent fuel could be accepted by the facility. Also needed is the establishment of a transportation infrastructure to ship the spent fuel casks to the facility, which could be done concurrently. This process could be expedited if existing federal facilities that have the requisite land, security and infrastructure could be used. The Department of Energy operates many national laboratories across the country as does the military with its numerous bases. While the PFS site has many political difficulties, it should also be considered a near-term option since it already has a Nuclear Regulatory Commission license.

There is a growing national taxpayer obligation to utilities for failure of the Department of Energy to remove spent fuel beginning in 1998 from nuclear plant sites according to contracts signed with the DOE. The costs are meant to cover the expenses utilities have incurred to build their own dry cask storage facilities at their sites. It is estimated that this obligation would total $11 Billion by 2020. By that time most of the utilities will have built their own Independent Spent Fuel Storage Installations (ISFSI) for which the government will have to pay under court decisions. These "sunk" costs affect the economics of building a central spent fuel storage facility since the marginal cost of operating an ISFSI while a nuclear plant is operating is relatively small. *Thus, when the ongoing costs of paying utilities for at-reactor storage are included as a sunk cost, these expenses plus those of building a centralized ISFSI and transporting spent fuel from operating sites is likely not to be economically justified since it does not reduce costs but adds to the costs of waste management.* This is ***not*** true for sites that have been decommissioned leaving only the ISFSI in place with relatively high annual operating costs which the government (taxpayer) is also obligated to pay. By clearing these sites, the government obligation ceases.

Decommissioned plants have stranded spent fuel stored on cleared nuclear plant sites. Economic analyses suggest that removal of spent fuel from these sites would be advantageous to the taxpayer but the size of the centralized interim storage facility would be considerably smaller since the economics of removing spent fuel from operating sites is not shown to be economic since the government has already "paid", by court ruling, for the capital cost of the facility at the plant sites. Once a larger number of nuclear plants are decommissioned the incentive for a centralized facility increases as the costs of operating these independent facilities are higher than a centralized facility. It is expected that by 2030, there will be an economic need for a centralized interim storage facility assuming all reactors have their licenses extended to 60 years.

An option to address the decommissioned plants is to co-locate decommissioned spent fuel at an existing decommissioned plant ISFSI in a community willing to host spent fuel from other plants. The chances of succeeding in this effort are unknown but depend on the willingness of the community and state to accept such a solution. This might be a first near-term test of the concept of finding volunteer sites in a community that understands the real meaning of spent fuel storage and past nuclear operations.

Should this option not work, it is recommended that a small 3,000 MTHM interim storage site be built to accommodate decommissioned sites which could be expanded in the future should a repository or a reprocessing facility not be available to accept spent fuel from future decommissioned sites. The location of this facility is quite flexible given that the transportation costs are relatively small.

The most recent capital cost estimate for a centralized ISFSI of 40,000 MTHM is about $560 Million which includes design, licensing, and construction of the storage pad, cask handling systems, and the rail infrastructure (locomotive, rail cars, transport casks, etc). Annual operating costs during loading are estimated to cost $ 290 million per year which includes the costs of the dual purpose canisters and storage overpacks, Fully loading this size ISFSI will take 20 years followed by a period of "unloading" and eventual decommissioning. The middle period of "caretaking" is estimated to cost about $4 million per year compared to caretaking decommissioned reactor costs for $8 million per year per site. The cost savings from consolidating the spent nuclear fuel from decommissioned sites is a compelling motivation for the federal government to create a centralized storage installation or facilitate transfers between decommissioned and active reactor sites.

The Private Fuel Storage company has updated its cost for a centralized facility in 2009 dollars to indicate that the cost of an ISFSI is $118 Million assuming it is run as a federal facility with no taxes paid. The cost of the rail infrastructure for the PFS includes transport casks, and all handling equipment is estimated to be $ 53 Million plus an additional rail extension to the site of $ 34 Million. Dedicated trains are assumed with 3 casks per train assumed in the analysis. Annual operating expenses for loading and unloading casks are approximately the same at $8.8 million. The PFS numbers do not include the costs of the waste canisters or storage overpacks which are assumed to be shipped to the site from the reactors.

The rail infrastructure costs are considerably different at $53.2 Million compared to EPRI's $366 million due largely to a smaller number of locomotives needed (4 vs. 14) and associated cask shipping cars for the same 2000 MTU per year of shipments to the interim storage site. PFS calculates the cost to ship 3 casks per train to be $75 per mile with dedicated trains. The PFS numbers shown reflect actual cost estimates for their project in Utah. Reconciliation of these numbers with EPRI cost assumptions is difficult but some obvious differences are that EPRI assumes only two casks per train and a site that has considerably higher capital cost for construction compared to what PFS expects.

Economic modeling of the net present value advantage comparing at-reactor storage for decommissioned sites with centralized storage at a number of reference locations in the east, west and mid-west show significant advantages for consolidation at centralized sites. A second important result is the relative indifference of costs to site location despite the significant real distance between sites. This implies that policy makers have wide flexibility in siting a central facility, a flexibility that should come in handy considering past experience.

Given the uncertainty of future nuclear energy policy in terms of reprocessing or direct disposal, interim storage should be considered as an integral part of the nation's waste management strategy and not only as a failure of the US to open a geological repository. While a repository is needed in all scenarios for the disposal of nuclear waste, the issue of what is to be disposed is still unresolved. Should the design of a repository be modified to make the spent fuel retrievable as a normal course of operation, it would allow more flexibility in the design of the US waste management system. Thus, the US could either build a central interim storage facility, use Yucca Mountain (assuming it continues) as an interim storage facility which could also be used as a repository, or build several interim storage facilities to make the siting somewhat easier. The last option would be the most costly.

A higher degree of confidence is required in the accuracy of the cost parameters used for transportation costs and O&M costs at active sites. If transportation costs are sufficiently low, and O&M costs sufficiently high, it would be cost-advantageous to consolidate SNF from active sites. Our analysis preliminarily supports this finding. This would create a regular stream of SNF to be consolidated, and in turn improve the relative costs of dedicated transport. However, when the sunk costs of existing at reactor ISFSI's are included in the overall cost, it is cheaper to keep the spent fuel at the active reactor sites. The dedicated train scenarios do show that the use of dedicated trains can be advantageous in terms of lowering the overall cost of the management of spent fuel in interim storage from all sites since it more effectively utilizes the dedicated train capacity.

Strong non-economic arguments can be made for building an interim storage facility. These include addressing the public concern about new plant construction and associated long term nuclear waste storage at plant sites, demonstrating the spent fuel can be safely transported, setting the stage for ultimately clearing out all sites either to a reprocessing plant or a repository. These are in addition to addressing the stranded nuclear waste at fully decommissioned nuclear plants. All are seen as important public confidence building initiatives to support the continued use of nuclear energy.

With the possible long term storage of spent fuel approaching 100 years in a combination of wet and dry storage, the technical data supporting such timelines was reviewed. The Nuclear Regulatory Commission has determined that in combination of wet and dry storage periods approaching 100 years are possible based on degradation analysis and monitoring. However the actual data supporting such a conclusion is limited to a physical inspection of a low burnup fuel assembly after 15 years of dry storage. High burnup fuels currently used and that are in storage have not been inspected to determine whether their behavior in storage will be similar to low burnup spent fuel. Assuming that the integrity of the storage canisters is not breached allowing for air ingress, storage for long periods should be possible despite continuing degradation mechanisms due to the reduction over time of the temperature of the spent fuel. Presently, NRC licenses dry cask storage installations for 20 year but is now considering extending ISFSI licenses to 40 years.

While the technical justification of long term dry cask storage may be established, additional technical justification will be needed to assure that spent fuel integrity (suitable for subsequent handling and transport) are met and that the integrity of the canisters can be maintained. This may require confirmatory research involving spent fuel inspections of high burnup fuel in dry casks and more extensive degradation modeling to provide adequate justification for expected periods of storage of the order of 100 years or more.

In conclusion, based on the economic analysis and the uncertain policy decisions of the future, the best strategy is for utilities to store spent fuel at reactor sites until such time that the fate of Yucca Mountain has been established and/or a decision is made on the timing of reprocessing technologies and their application in the United States. The only exception to this conclusion is that for decommissioned sites. Once those decisions are made, and according to our model, the suggested alternative is to co-locate interim storage with the reprocessing facility to avoid additional transport charges as well as security risks associated with the transportation of spent fuel or reprocessed waste. It is our expectation that the technologies to implement reprocessing and fuel fabrication in the US for either recycling in light water reactors or use in fast reactors will not be available until 2030 to 2040 time frame. This means that the only reasonable option that will minimize taxpayer dollars is continued on-site storage at operating nuclear plants, which utilities will be capable of cost-effectively doing for the duration of their operating licenses.

For decommissioned plants, consolidating spent fuel makes economic and policy sense either at a national laboratory site, a new central interim storage facility of about 3,000 MTHM or at an existing plant that is currently storing spent fuel. All of these depend on the host town and state willing to accept this near term solution. This facility would provide the needed public confidence to demonstrate that spent fuel can be shipped from operating sites and safely stored at a interim location pending either reprocessing or disposal.

A final observation based on the history of the US nuclear waste policy is that due to the long time frames for development and deployment, a consistent, durable, and stable national policy is needed to successfully address the ultimate question of what are we, as a nation, going to do with nuclear waste.

Recommendations

Given this long term horizon, several recommendations are made:

1. Remove spent fuel from decommissioned reactor sites to an existing secure national facility that has the infrastructure to support long term storage. Should this not be possible, build a centralized interim storage facility capable of storing 3,000 MTHM of spent fuel from decommissioned reactors that could be expanded as needed when other operating reactor sites are decommissioned in the 2030 time frame.

2. If a policy decision is made on recycling, build a single interim storage facility at the proposed site of the nation's reprocessing and recycling plant. This would minimize future storage and transportation costs and minimize proliferation risks. Should the nation decide to transmute nuclear wastes, this facility could also be the location of a fast transmuter reactor.

3. To provide additional flexibility and greater certainty in the ultimate solution to the nuclear waste problem, redesign Yucca Mountain (or any future repository) for true retrievablility to allow for Yucca Mountain to become an underground retrievable storage facility should the policy decision on reprocessing be delayed. This would provide secure underground storage and if the decision is made not to reprocess, this site could become the final waste disposal solution. The only disadvantage is that it would require an additional transportation step to the reprocessing plant should the policy decision support such a path.

4. Should politics and lawsuits permit a faster solution, the DOE should acquire the already NRC licensed Private Fuel Storage site in Utah for an interim storage site. This would provide a quick and less costly solution to siting of an interim storage site; provide relief to utilities and ultimately the government on liabilities associated with failure to meet contractual obligations; and begin the demonstration of transportation of nuclear materials which will be needed in the future for the longer term options being considered. This solution would be especially valuable for clearing decommissioned sites, ending the government obligation to pay for contract defaults.

5. Introduce legislative to remove the linkage between the repository and the construction of an interim storage facility.

6. Conduct confirmatory research to increase confidence in the technical feasibility of long term dry cask storage to assure that after storage for a long time, the spent fuel can be safely transported to either a repository or reprocessing plant.

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1.0 BACKGROUND

1.1 Used Nuclear Fuel (Spent Fuel)

In the course of generating electricity, nuclear plants create small amounts of highly radioactive waste in the form of spent nuclear fuel (SNF). This spent fuel constitutes a significant hazard to human safety and must be properly stored and disposed of in order to prevent negative health impacts. The radioactivity and extreme longevity of this waste has made management of spent nuclear fuel a major policy challenge for virtually every nuclear power generating country in the world, and the debate over how best to dispose of nuclear waste has become a contentious issue, especially within the United States.

The end of 2008 the United States commercial nuclear waste inventory stood at approximately 60,000 metric tons of heavy metal (MTHM). Roughly 47,000 MTHM are held in spent fuel pools (commonly referred to as "wet storage"), while the remaining 13,000 MTHM have been placed in casks that are collectively referred to as "dry storage[1]." Roughly 2,200 MTHM are produced each year by the existing nuclear fleet[2].

There are currently 104 operating and 14 permanently shutdown commercial nuclear power reactors in the United States; four of these shutdown reactors are located at sites with other operating reactors. The other ten shutdown reactors are located at nine sites with no current nuclear operations. In the future, as more reactors shut down, the number of stranded SNF storage sites will grow considerably, raising the cost to not only the utilities, but ultimately the U.S. taxpayer, as the U.S. government has been held liable for breach of its contract to take receipt of the SNF starting in 1998.

The marginal cost of SNF storage at a site with ongoing nuclear operations is relatively small— most of the related operations and maintenance (O&M) can be integrated with existing site operations and result in small additional overhead. However, at sites with no current nuclear operations, the cost of SNF storage reaches about $8 million dollars per year per site. The cost of maintaining SNF at sites with no ongoing reactor operations provides the primary economic motivation for consolidation of SNF at a central facility or other reactors.

Spent nuclear fuel has the following characteristics:

- Small volume and mass. The energy release from nuclear reactions is about a million times greater than from the burning of fossil fuels; consequently, the quantities of SNF that are generated are small. While the cost of SNF management per ton of SNF is large, the cost of SNF management including disposal is small relative to the cost of electricity and is estimated at 1-2% of the cost of electricity.

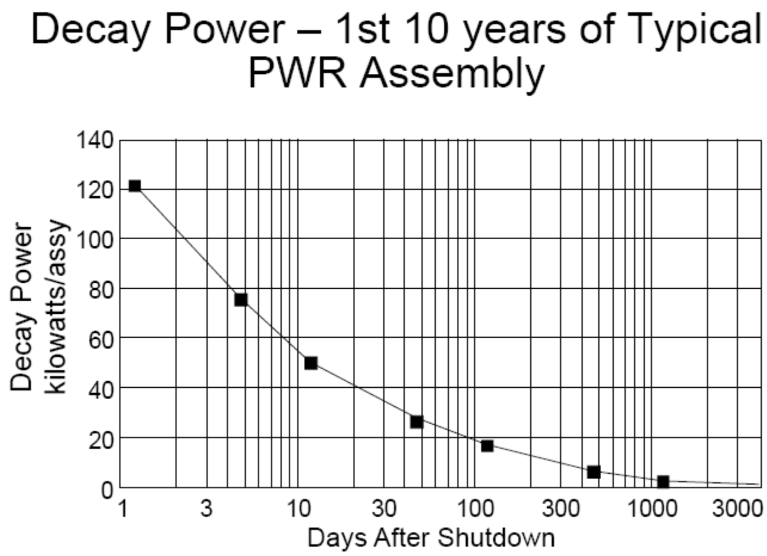


Figure 1: Typical Decay Heat Curve for Spent Fuel

- Fuel value. Existing reactors recover slightly less than 1% of the energy value of the initial mined uranium. Advanced breeder reactors could recover most of the energy value of the uranium by appropriate recycle of the SNF and use of the depleted uranium from the uranium enrichment process. Recycle of SNF is currently uneconomic; but, SNF may be a valuable fuel in the future.
- Radioactive decay. Radioactive materials decay to non-radioactive materials with time and in the decay process generate heat. The radioactivity and heat generation of SNF decreases with time. Longer storage periods make the design of the repository less complex which is an advantage in terms of a lower heat load which is a limiting design constraint. Shown on Figure 1 is the reduction in decay heat with time.

In all countries with all fuel cycles, SNF or the equivalent high-level waste from recycle of the SNF is expected to be stored for a minimum of 30 to 60 years before disposal—independent of whether the particular country has an operational repository. The decay heat from the SNF limits the number of SNF assemblies that can be placed in a transport, storage, or disposal package. If too much decay heat is produced in a single package, the SNF may overheat and be damaged. As the decay heat decreases, the amount of SNF that can be placed in a cask increases. If SNF is cooled in reactor pools for five to fifteen years, it allows the use of lower-cost SNF storage casks for longer-term storage. If SNF is stored at the reactor for a decade before transport, it allows the use of larger transport casks and reduces the number of shipments required. At the repository, aging SNF decreases the size of the repository, decreases repository costs, and improves long-term repository performance.

SNF may also be stored for other reasons: (1) as a potential future energy resource, (2) to reduce the costs of recycle by reducing the radioactivity of the SNF before it is processed, and (3) provide additional time for the siting of a geological repository.

1.2 Wet Storage

Spent fuel pools are 40 foot deep (Figure 2) water-filled storage areas with submerged holding racks capable of safely storing spent fuel assemblies after they have been removed from a reactor. The water and concrete of the pool shields reactor workers from the radiation of the spent fuel, and pumps actively remove decay heat produced by the assemblies. For the first five years after discharge from a reactor, spent fuel assemblies generate too much heat to be safely dry stored—active cooling is needed to prevent damage to the fuel.

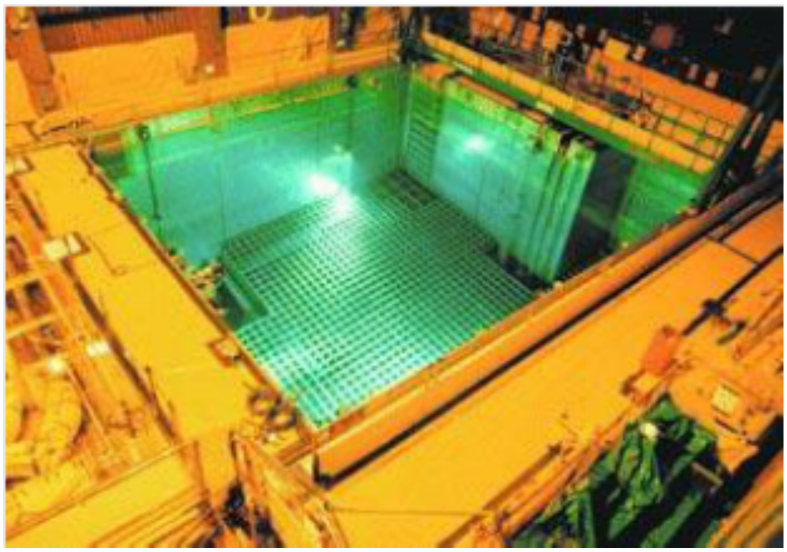


Figure 2: Wet Storage System - Spent Fuel Pool

When the current generation of reactors was being built, fuel storage pools were intended to provide only a short cooling period before the assemblies would be sent to a storage or reprocessing site— as a result, the pools were constructed with only a small storage capacity (typically one and one-third of a core's full number of assemblies). The ban on spent fuel reprocessing in the 1970's and the failure to build a national repository have made storage at spent fuel pools the de facto policy choice of the United States, and reactor operators, in response, have retrofitted their pools in an effort to increase capacity. By using more densely packed storage racks and adding neutron absorbers, utilities were able to expand their waste-storage potential, but ultimately the size of the pool and the need to prevent criticality places a ceiling on what retrofits can accomplish. After a time, the gains from retrofitting were exhausted, and since 1986, more and more fuel storage pools have begun to reach their maximum holding capacity (see Figure 3).

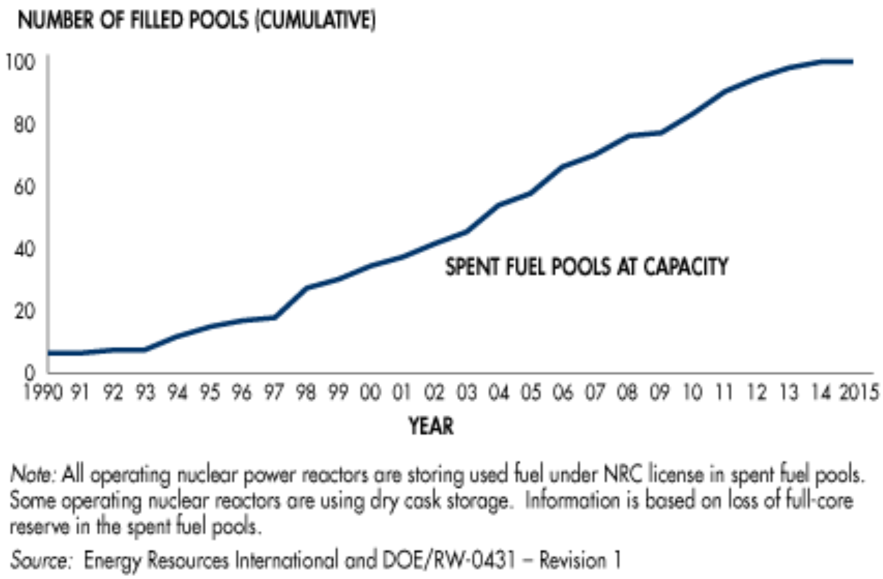


Figure 3: Status of Filled Spent Fuel Pools

Currently, the large majority of the spent fuel pools in the United States are filled to capacity, with most of the remainder on track to be filled by 2015. By 2017, all but one site (which was constructed with sufficient pool storage capacity to store all of the SNF produced during the reactor's lifetime) will be at capacity, necessitating the greater use of dry storage.

1.3 Dry Storage

In the early 1980's, in response to the overcrowding of fuel pools, the nuclear industry began to explore other temporary storage techniques. Spent fuel assemblies that have decayed sufficiently and thereby emitting less heat can be transferred into dry storage systems consisting of either thick-walled metal casks, or thin-walled canisters surrounded by a metal or concrete outer shell for shielding purpose. Casks or canisters are passively cooled by ambient air. Typical storage casks are shown on Figure 4 which are either vertical or horizontal. Thus far utilities have transferred 13,000 MTHM of SNF to above-ground dry storage systems. These storage casks are typically stored on a concrete pad with significant security systems and fencing. Other configurations can also be used, such as vaults. In a vault, the spent fuel is stored in a large concrete structure whose exterior serves as the radiation shielding.

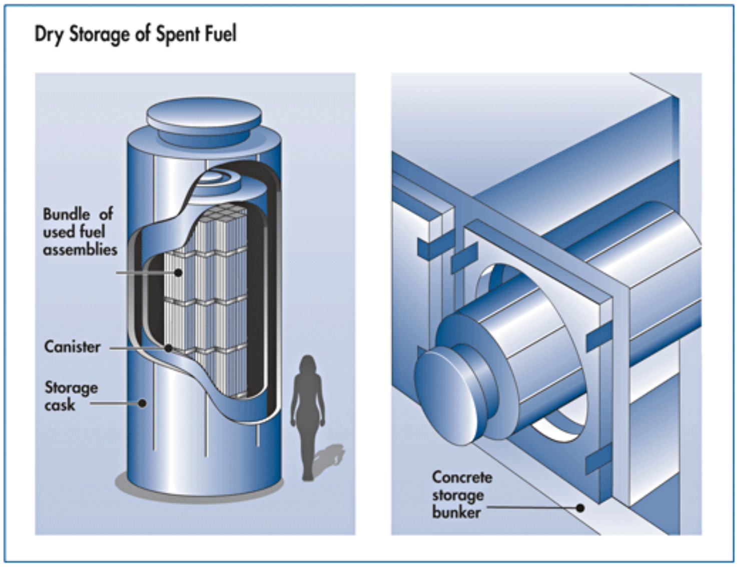


Figure 4: Dry Cask Storage System – Vertical on left - Horizontal on right

The interior of the structure consists of a number of storage racks into which spent fuel assemblies can be placed. Spent fuel canisters are filled with inert helium gas to prevent degradation by oxidation and use either seal welding for the canister designs or bolting with metallic seals for the thick-walled casks. Welded canisters are then placed in concrete cylinders (which provide the radiation shielding) fitted with inner metal liners or separate metal enclosures.

The popularity of cask systems among reactor operators stems from the casks' inherent flexibility. Not only do casks allow for modular expansion of storage capabilities, but "dual purpose" licensed casks can also be used for transportation of nuclear waste. Some casks are storage-only casks not suitable for transportation which requires some means of repackaging into transport casks needed for shipment. This is most easily done by placing these casks back into spent fuel pools; however dry cask systems are being developed for plants that have decommissioned their spent fuel pools. Some cask vendors developed "Multiple Purpose Containers" (MPCs) which they hoped would be suitable for storage, transport and disposal believing that DOE's plans would in the future accommodate such casks for disposal

Before transferring spent fuel to dry casks, nuclear power plants (or other independent sites) must obtain an Independent Spent Fuel Storage Installation (ISFSI) license under the Nuclear Regulatory Commission (NRC). These licenses come in two types. A "site-specific license," available to both nuclear plants and independent sites, authorizes operation subject to the NRC's standard licensing requirements and specifies the type of storage system to be used. Alternatively, nuclear power plant operators may apply for a "general license" using NRC-approved dry storage casks. This option allows plants to avoid repeating certain evaluations (such as environmental impact or seismic reviews) that were previously conducted for the plant's operating license. As June, 2009, 49 sites hold ISFSI licenses in over 30 states. Shown on Figure 5 is a horizontal ISFSI storing dry casks.

Figure 5: Independent Spent Fuel Installation - Dry Cask Storage

The Nuclear Regulatory Commission has concluded that dry cask storage of nuclear waste is a safe method of storage, recently estimating that dry cask storage carries a per-cask risk of cask-failure induced fatality equal to 1.8×10^{-12} in the first year of operation and 3.2×10^{-14} per year for each subsequent year of storage[3].

In December, 2008, the Department of Energy issued a report to Congress on the regulatory issues associated with the creation of a large, independent site for centralized interim storage and concluded that it would take six years to complete such a facility— three years for licensing and three years for construction— making 2015 the soonest date that operations could begin[4]. If an existing site were used, operations could begin sooner, but significant political and regulatory issues would need to be resolved in order to enable this strategy.

SNF storage is a required component of the nuclear fuel cycle independent of the choice of fuel cycle. In the United States, dry cask storage will be the long-term storage option since spent fuel pools are basically filled. The questions are thus where should this SNF be stored and under what conditions should it be stored? There are three primary SNF storage options.

- At reactor sites: in both dry casks and wet storage pools.
- Centralized Storage: SNF may be moved to centralized facilities for long-term SNF storage. This could be a stand-alone facility, at a potential future reprocessing plant site, or as a surface facility at the repository site. In the U.S., the Department of Energy has built centralized storage facilities for government-owned SNF in Idaho and Washington. Sweden stores most SNF in the CLAB Spent Fuel Storage Facility wet storage facility at Oskarsham, Sweden. France stores its SNF in the spent fuel pool complex at the La Hague reprocessing plant and has two dry storage facilities for high-level waste glass. The design of the proposed U.S. Yucca Mountain repository has a large SNF storage area to age the SNF and reduce decay heat levels before emplacement of wastes in the repository.
- Ventilated repository: SNF with limited aging can be disposed of in a repository if the repository is ventilated to remove decay heat. The repository is closed only after sufficient storage time sufficient to allow the SNF decay heat to decrease to low levels. The design of the proposed U.S. YMR has delayed closure with active

repository ventilation period of 50 years for retrievability and to allow in-repository aging of the SNF. The Nuclear Waste Technical Review Board Studies have shown[5] that up to 100 years of ventilation could accommodate much of the US spent fuel inventory without violating temperature limitations today.

1.4 Location and Transportation Options of Spent Nuclear Fuel

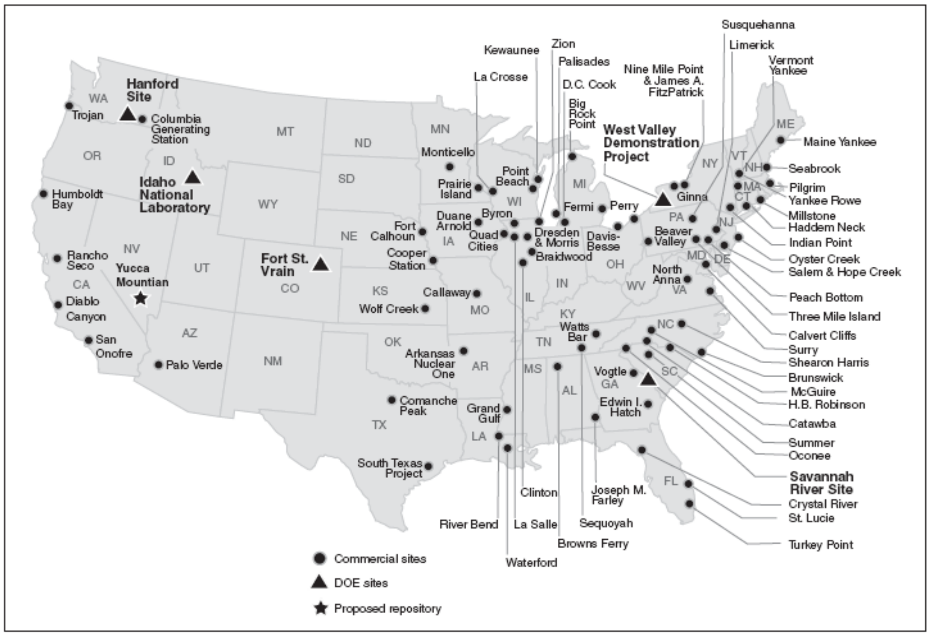
Spent nuclear fuel and high level nuclear waste is distributed widely across the United States, with the bulk of SNF located in the eastern United States

Figure 6). DOE, in the course of planning for Yucca Mountain, has proposed shipment schemes for each of the 72 commercial sites containing SNF and highlighted rail lines that they would utilize. 25 sites are without direct rail access; of these, 12 are within roughly 10 road miles of the nearest usable rail line (Browns Ferry, Callaway, Cooper Station, Diablo Canyon, Fort Calhoun, Haddam Neck, Indian Point, Oconee, Oyster Creek, Palisades, St. Lucie, and Yankee Rowe), 9 are within 50 miles (Big Rock Point, Calvert Cliffs, Clinton, Grand Gulf, Salem/Hope Creek, Kewaunee, Peach Bottom, Point Beach, and Surry), and 4 are within 200 miles (Crystal River, Humboldt Bay, Lacrosse, and Turkey Point). Of these 25 sites, a majority could use barge transport to a port-rail facility in lieu of truck transport.

Estimating the cost of transportation is a difficult issue. Rail transportation is generally held to be preferable to truck transportation from a cost perspective, if one presumes the existence of a rail line connecting the points of departure and arrival. However, if no such rail line exists, truck transportation may be more cost effective, depending upon circumstance. The DOE has determined that rail is the preferred alternative for shipment of spent fuel using dedicated trains. Shown on Figure 7 are the major rail lines available for cross-country shipments.

Water-based transportation is an interesting alternative — Japan's and Sweden's experience with sea transport of spent nuclear fuel suggests that for some sites, water transport may be a cost effective method of transcontinental or regional transfer. The question of whether or not sea transport is cost effective plays an especially important role if the decision is made to site a central installation near the coastal United States. The option of transcontinental sea shipment of SNF, if pursued, would require some work to guarantee the availability of the Panama Canal for future shipping.

Transportation of spent fuel assemblies poses a more challenging set of safety risks than simple dry cask storage, but both technical analyses and historical experience suggest that these risks are identifiable and manageable. Worldwide, more than 88,000 MTHM have been transported by ship, truck, and train[6]. In the United States over 3000 shipments of spent nuclear fuel have occurred in the last 40 years traveling over 1.7 million miles with only 9 accidents (only 5 involved any radioactive materials) with no release of any radioactive materials. This is due to the robustness of the design of the shipping casks.[7],[8]



Source: DOE.

Figure 6: Location of Spent Nuclear Fuel and High Level Waste

1.5 Reprocessing

Prior to 1972, nuclear utilities shipped spent fuel to a reprocessing plant in West Valley, New York. In 1977, the national policy was changed by President Jimmy Carter who banned commercial reprocessing. President Carter was concerned that the spread of reprocessing around the world would increase nuclear weapons proliferation and felt that if the US banned reprocessing it would send a strong message to other nations of the world. Unfortunately, this policy objective was not realized as other nations continued to reprocess and developed their own nuclear capabilities. For the utilities, the Carter decision meant was that they would have to continue storing used fuel in their spent fuel pools. At present there is no ban on reprocessing in the US but currently the cost of reprocessing in the light water reactor fuel cycle is not economic compared to purchasing fresh uranium fuel.

1.6 Interagency Review Group

In 1978 President Carter convened an "Interagency Review Group on Nuclear Waste Management" (IRG) to explore all options and develop a "coherent and comprehensive national nuclear waste policy"[9] since at this point, there was no clear path for the disposal of spent nuclear fuel from commercial nuclear plants, nor high level waste from government defense facilities. After about two years of extensive study, interagency reviews, stakeholder comments, a report[10] was issued in 1979 which made several recommendations that led to the Nuclear Waste Policy Act of 1982[11].

The key recommendations of the IRG were to establish a repository screening process which would lead to the down-selection of several alternatives with the expectation that two repositories would be sited, one in the east and another in the west; the establishment of a schedule to take spent fuel for disposal from US utilities by 1998; requiring that each utility sign a contract with DOE which stipulated that DOE would take the spent fuel beginning in 1998 and that waste fee be collected from nuclear generated electricity to pay for disposal; and lastly, requiring that the standards for the repository be set by the Environmental Protection Agency (EPA) with the facility licensed by the Nuclear Regulatory Commission according to EPA standards. It is interesting to note that the 1982 Waste Policy Act also called for the construction of an interim spent fuel storage facility of 1,900 MTHM for spent fuel from civilian reactors.

By 1986, DOE named 5 candidate sites and selected three, one each in Nevada, Texas and Washington State for detailed site characterization from which one would be selected as the site for detailed design and licensing. That same year, DOE postponed the development of the second repository in the Midwest and East due to strong political opposition. In March 1987, DOE submitted a proposal to Congress (required under the Act) to build and operate a Monitored Retrievable Storage facility at the former Clinch River Breeder Reactor Project site near Oak Ridge Tennessee. This area was considered to be “nuclear friendly” due to the presence of the Oak Ridge National Laboratory. However, there was intense opposition from state and federal officials.

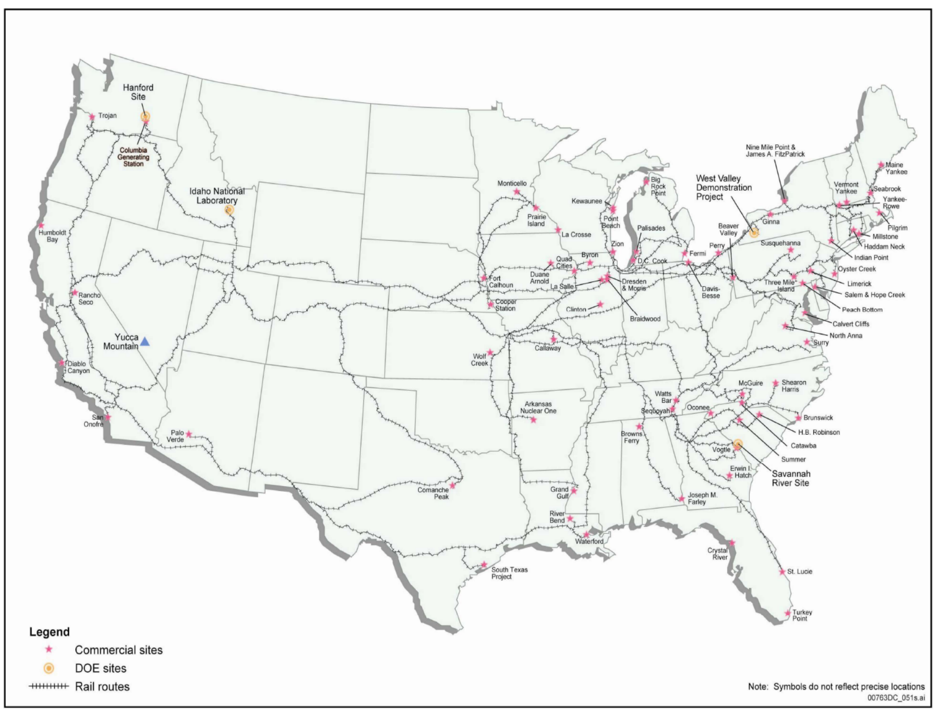


Figure 7: Major US Railroad Lines

1.7 Monitored Retrievable Storage

Given the frustratingly slow progress on site selection of a repository, the costly site characterization process (at $1 Billion per site) and the mounting opposition to interim and final disposal, Congress passed an amendment to the 1982 Act in 1987 which is the current law today. The 1987 Amendments included the following provisions:

- DOE should characterize only Yucca Mountain in Nevada,
- Officially postpone the search for a second repository
- Order DOE to build a Monitored Retrievable Storage facility of much larger size (10,000 MTHM)
- *Prohibited building an MRS in Tennessee*
- *Prohibited studies of repositories in granite and other crystalline rock*
- Established an Monitored Retrievable Storage Review Commission
- Created the Office of the Nuclear Waste Negotiator to assist in siting an MRS
- Linked the timing of construction of the MRS to progress on the repository
- Established the Nuclear Waste Technical Review Board
- Offered Nevada financial benefits in exchange for giving up right to object.

Congress also found in the 1987 Amendments Act that "long term storage of highly radioactive waste in MRS facilities is an option for safe and reliable waste management"[12]. ***However, Congress imposed several restrictions on the MRS.*** These included:

- Not allowing DOE to select an MRS until the Secretary of Energy recommended a site for the repository to the President.
- Stipulating that a license to construct the MRS could not be issued unless an NRC license was issued for the construction of the repository
- Limiting the initial size of the MRS to 10,000 MTHM.

These provisions were aimed at making the job of the Nuclear Waste Negotiator somewhat easier since the interim storage sites could be assured that should they volunteer for the MRS, it would not be permanent. These provisions also made the justification of an MRS somewhat difficult since the need for such a facility was questionable unless the Yucca Mountain project was substantially delayed.

The MRS Commission issued its report[13] two years later in 1989 which concluded that:

- Due to the linkage to the repository, that the earliest the MRS would be available would be three years before the repository opens thus reducing its need and value.
- If the linkages were removed, the value of the MRS would be increased since it would be available much earlier.
- Some interim storage would be necessary for utilities on an emergency basis to keep plants operating.
- The MRS would be more costly to overall waste management system than without MRS.
- The relative cost would decrease if the repository was considerably delayed.

The recommendation of the Commission was to build an MRS with a capacity of 5,000 MTHM and reconsider the MRS issue in 2000.

1.8 Nuclear Waste Negotiator

With release of this report, the Office of the Nuclear Waste negotiator was filled in 1990. He set out to find volunteer sites to host interim storage facilities across the country. He was empowered to negotiate benefits and work out details of the agreements with host towns, Native American tribes and states. He was operating independently of DOE but was to bring to DOE a number of potentially interested communities for funding grants to investigate the details of what it would mean to be a host to an MRS facility. The legislation also required that ***Congress approve*** the agreement that was reached by the Nuclear Waste Negotiator (NWN).

The first NWN was David Leroy, a distinguished attorney and former Attorney General of Idaho. In June of 1991, he sent out formal invitations to all states, local governments and Indian tribes to express interest in receiving financial grants to assess the feasibility of siting an MRS. The responses to this invitation came from Indian tribes – the Mescaleros of New Mexico, Skull Valley Band of the Goshute Indian tribe in Utah and Paiutes in Oregon plus others. Negotiations continued for several years. The challenge faced by the NWN was getting agreements from the state governors and state politicians (local and national) in addition to agreements from the Native American tribes who believed that they had sovereign rights. In September of 1991, the General Accounting Office concluded that the operation of an MRS was unlikely by 1998 due to congressional linkages, lack of progress by the negotiator and difficulty in getting states to agree to hosting an MRS[14].

In subsequent years, several proposals with the Mescalero and Goshute tribes were actively being negotiated. *When it appeared that progress was being made with these two tribes, due to the strong opposition of the states,* ***Congress in 1993 blocked*** *funding for future grants in October of 1993 (P.L. 103-126)* essentially killing government prospects of building an MRS and sealing the fate of DOE in terms of not being able to begin moving spent fuel from utility sites as called for in their contracts.

In 1993, former Congressman Richard Stallings (Idaho) was named by President Clinton as the new waste negotiator. Despite the handicaps imposed by Congress, he continued to try to find a volunteer site meeting privately with governors and other state leaders to see if progress could be made. His efforts were unsuccessful and in 1995, *Congress allowed the authority of the waste negotiator to expire in January of 1995.* The office and effort was closed without any siting agreements. In essence, the effort to find a community willing to host an MRS with negotiated benefits had failed.

In an interview[15] following his departure from office, Stallings offered the following explanations for the failure.

- "It was a very hard sell"
- Public fear of nuclear despite the safety of storage
- Political realities of elections – governors and state leaders could not be seen as supporting bringing nuclear waste into their state
- Congressional belief that if the MRS was built, pressure would be taken off the Yucca Mountain disposal site project.

In a recent discussion with David Leroy, the first nuclear waste negotiator, his view is that the volunteer siting process can work provided that the negotiator is given the resources and time to negotiate the terms of an interim storage facility and benefit package, but recognizes that the lack of a proposed repository makes the process more difficult[16].

What is apparent in the history of attempts to site an interim storage facility is that Congress has played a key role in preventing the siting due largely to local state objections.

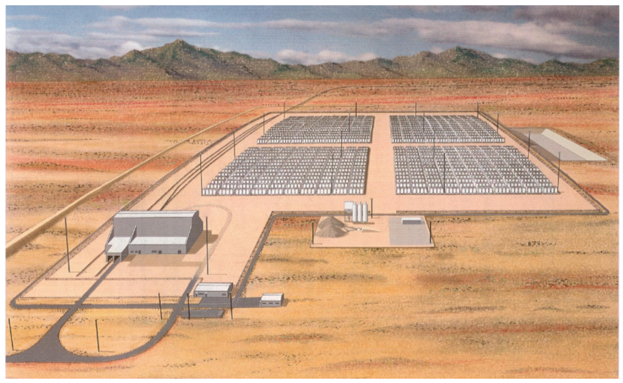


Figure 8: Proposed Private Fuel Storage Facility in Utah

1.9 Private Fuel Storage

With the failure of the government-supported MRS facility, a group of nine utilities formed the Private Fuel Storage Company in an effort to pick up where the government left off. This consortium began working with the Skull Valley Band of the Goshute Indian tribe in Utah which was one of the candidate sites. The PFS consortium submitted a license to the Nuclear Regulatory Commission for an “Independent Fuel Storage Installation” (ISFSI) for 40,000 MTHM in 1997. After a nine year licensing process and legal battles, on February 21, 2006, the NRC issued a license to build the PFS interim storage facility on the Goshute reservation. This license is good for 20 years with another 20-year renewal possible. Since the PFS project will not take “title” to the spent fuel, the utilities will be obligated to take the spent fuel back once the license expires if DOE did not take the spent fuel by then.

The state of Utah, including the congressional delegation, has strongly fought against the PFS project, challenging the license in many court proceedings. Examples of federal interference in this project are two Department of Interior (DOI) decisions. The first is a Bureau of Indian Affairs disapproval (of a previously approved) lease of tribal trust lands to PFS and a Bureau of Land Management rejection of a right of way to transport spent fuel to the site by rail. One of the reasons stated by DOI was that “there was too much risk that the waste could remain at the site indefinitely”. In response, the Goshute tribe and PFS filed a federal lawsuit in July, 2007 to overturn these decisions contending “the Interior Department was motivated by political pressure from the state of Utah”[17]. This suit is still pending. Should these legal issues be resolved, in theory, Private Fuel Storage could start construction of the facility.

1.10 The Utility Spent Fuel Storage Situation

Due to the political impasse of siting an interim spent fuel storage facility, utilities were forced to deal with spent fuel storage by re-racking the spent fuel pools and building dry cask storage systems to maintain the ability to operate their power plants. These were costly facilities that required new or amended NRC license applications. Some plants are completely decommissioned (dismantled and site restored) with the only remaining nuclear installation the storage pad with spent fuel in dry storage casks. Shown on Figure 9 below is the Yankee Atomic Electric site in Rowe, Massachusetts as a typical example of a decommissioned site.

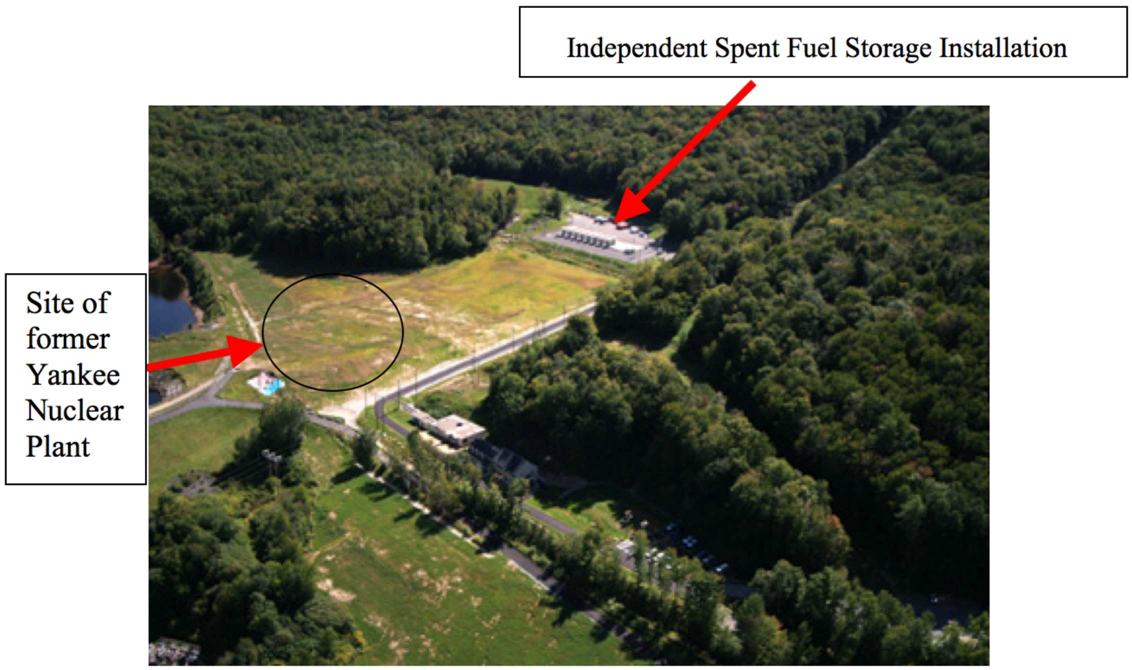


Figure 9: Decommissioned Yankee Atomic Electric Company site with ISFSI

The current status of used fuel inventory is shown on Table 1. As of the end of 2008, there are 60,059 MTHM (~210,000 spent fuel assemblies) in storage; of this there are about 47,500 MTHM in wet storage. There were approximately 13,000 MTHM stored in over 1,000 casks at 44 plant sites in 31 states. The key point is that utilities have had to build dry cask storage facilities since the spent fuel pools have been "filled". Table 1 also breaks down the dry cask systems into several types: those that hold bare fuel in non-transportable forms that need to be repackaged; spent fuel that is stored in storage only casks; spent fuel stored in Dual Purpose Containers (DPC) that are suitable for transport and Transport, Aging and Disposal (TAD) canisters which the Department of Energy is expected to make available in 2013 assuming congressional funding. This inventory will increase time as also shown on Table 1 assuming no new nuclear plants. By 2040, the spent fuel in storage inventory will double to 130,000 MTHM in pools and over 7,000 dry casks.

Shown on Table 2 are the trends in waste storage systems in terms of increasing storage capacity. The obvious trend is increased capacity for storage systems, which is in the opposite direction from the casks DOE is designing for direct disposal. If TADs are to be deployed in large numbers, the number of casks to be handled will grow considerably as will the number of shipments. It should also be noted that the utilities are currently loading casks of higher burnup fuel with higher heat loads making them unsuitable for direct disposal, since they exceed the design limits for the repository. This will require either a longer ventilation period in the repository or repackaging the spent fuel for lower heat load limits or storing for a longer period allowing for radioactive decay. All would be costly alternatives.

Table 1. Current and Projected Spent Fuel Inventory

Used Fuel Inventory Projections
Scenario 1 – Current Plants/TADs in '13

Year	MTHM Total	MTHM Pools	MTHM Dry Storage	Dry Cask Systems							
				Total	Non-trans bare fuel	Non-trans, cani-ster	Trans bare fuel	Trans bare fuel, trans license pending	DPCs	DPCs trans license pending	TADs
2008	60,059	47,465	12,594	1,073	29	199	41	87	571	146	0
2009	62,432	48,651	13,781	1,164	29	204	44	88	617	182	0
2010	64,461	49,666	14,795	1,242	29	209	47	89	651	217	0
2020	87,193	57,083	30,110	2,894	29	219	144	0	1069	0	1433
2030	110,383	58,207	52,176	5,431	29	219	144	0	1069	0	3970
2040	130,013	58,207	71,806	7,687	29	219	144	0	1069	0	6226

NEI

Table 2 Trends in Dry Cask Storage Systems

Dry Storage System Trends

Dry Storage System	Capacity per cask # of assemblies		Capacity per cask MTHM	
	BWR	PWR	BWR	PWR
Typical pre-2000 system	52	24	9.4	10.8
Typical present day system	65 (avg)	32	11.7	14.4
Future systems (max. currently licensed)	87	37	16.7	15.7
TADs	44	21	7.9	9.5

NEI

Table 3 Projections of Used Fuel Locations

Used Fuel Locations

	Shutdown Plants*				Operating Plants			
	Pool Storage		Dry Cask Storage		Pool Storage		Dry Cask Storage	
	Sites	States	Sites	States	Sites	States	Sites	States
1980	1	1	0	0	46	24	0	0
1990	4	3	0	0	69	33	3	2
2000	9	8	1	1	65	31	14	11
2008	3	3	7	7	65	31	37	27
2009	2	2	8	7	65	31	41	27
2010	1	1	9	8	65	31	45	27
2020	0	0	10	9	68	31	63	30
2030	4	4	10	9	64	31	59	30
2040	22	17	36	24	34	21	34	21

* Assumes all plants operate for 60 years

NEI

1.11 Utility Breach of Contract Lawsuits Against DOE

When the Department of Energy's plans for opening Yucca Mountain were delayed, in 1998, 41 utilities filed suit against the Department for breach of contract for not taking spent fuel according to their individual contracts. These lawsuits increased in number and were largely successful for the utilities in that the Federal Court of Claims agreed that there was indeed a contract breach and that the Department of Energy was to compensate the utilities for the extra cost associated with on site storage. This decision, which remains in effect today, has created a potential obligation to the federal treasury of up to $11 Billion if DOE does not begin taking spent fuel from utility sites by 2020. The Federal Court of Claims also made the decision that the compensation to utilities should not come from the Nuclear Waste fund but rather from the Federal Judgment Fund which is a taxpayer funded obligation of the federal government to pay for suits lost by the government.

Thus far, the Judgment Fund has paid over $290 million to 4 electric utilities in settlements. The rest of the cases are waiting final damage claim settlements. Under the settlements and suits, DOE pays for the cost of on site storage which will accumulate as long as DOE does not remove fuel from the utility sites according to the "waste acceptance" schedule as called for in the contracts on an as-discharged basis from the reactors. Even if DOE begins taking spent fuel in 2020, there will be an effective 20-year backlog, further accumulating compensation penalties to be paid for by the taxpayer. This situation may favor building interim storage sites operated by the federal government. This will be analyzed later in this chapter.

The power of the utility contracts applies to all spent fuel discharged from nuclear power plants regardless of their operating license periods. The legislated capacity of Yucca Mountain is 70,000 MTHM of which 63,000 MT is to come from the commercial nuclear industry. Projections of spent fuel discharged from reactors with full license extension of 60 years will result in an additional 40,000 MTHM which means that either Yucca Mountain's legislative capacity limit be lifted, another repository be opened or additional interim storage facilities be built to handle all this spent fuel or the taxpayer will continue to pay the damages for DOE's failure to start taking spent fuel in 1998.

At the present time, there are no government plans for siting interim storage facilities in the US. The Obama Administration has stated they would seek to cancel the Yucca Mountain project, and a new two-year study is about to begin by DOE's newly created "Blue Ribbon Commission" to investigate all nuclear waste options again including reprocessing, transmutation and disposal.. The law of the land still calls for direct disposal of spent nuclear fuel in Yucca Mountain should it be licensed by the Nuclear Regulatory Commission. Unless Congress changes that law, it must be followed.

What this means for utilities is that they will be storing spent fuel at their sites for a long time and the liability of the federal government will grow until DOE begins removing spent fuel from utility sites. As noted earlier, there is no place to ship the spent fuel since government operated interim storage facilities are legislatively prohibited since it is linked to progress on Yucca Mountain which this administration wants to cancel. This leaves the government in a difficult dilemma essentially requiring a law change to allow for interim storage construction unlinked to a repository; or opening Yucca Mountain assuming a reversal in administration policy and.a positive NRC finding in the licensing process or finding and licensing another repository.

Given the past failures of siting an interim storage facility with a named repository (Yucca Mountain), the prospects for finding a new volunteer site are judged to be lower since there is no designated place to dispose of high level nuclear waste.

Given this scenario, even if Yucca Mountain was licensed by NRC and Congress funded its construction, by 2020 there will approximately 290,000 spent fuel assemblies in storage. By 2040, this number grows to 420,000 without any new plants being built. By 2020 essentially all plants will have Independent Spent Fuel Storage Installations at plant sites.

2.0 OPTIONS FOR INTERIM STORAGE

The options for interim storage are few: (1) Spent fuel and high level waste can remain where it currently is at existing power plant sites and at DOE facilities; or (2) new regional nuclear waste storage facilities that have yet to be identified. The Navy has consolidated its spent fuel storage at the Idaho National Laboratory where the state and DOE have signed an agreement to have all the nuclear waste including spent fuel to be removed from the state by 2035. The Department of Energy has also established Savannah River Site as the place to store spent fuel from foreign research reactors which they have collected from US supplied fuel provided to these nations. In addition, government spent fuel and nuclear waste is stored at Hanford, Washington.

The current public debate on what to do with spent fuel is trending towards the siting of additional regional storage facilities. Based on experience to date and the obstacles that have been placed in achieving regional storage, it is expected that the minimum time to build a regional facility is at least 10 years. The siting process requires NRC approval. A 10 CFR Part 72 license would be required for the construction of an Independent Spent Fuel Storage Installation. The biggest challenge however is finding a site for such a facility which would require local and state approval to be successful.

Having found a site and obtained a license, the construction of a fuel handling facility and a large parking lot for the storage of spent fuel casks is not seen to be a problem. Utilities have built 44 ISFSI's at their sites. Each facility costs about $35 million with each storage cask costing about $750,000 that can store about 20-30 PWR assemblies and about 60 BWR assemblies.

2.1 Cost of Independent Spent Fuel Storage Facilities

Estimates for the cost of independent fuel storage facilities have been made by the Department of Energy for the Monitored Retrievable Storage project, the Electric Power Research Institute, the Private Fuel Storage Company and many utilities who have built them on reactor sites. A recent study comes from the Electric Power Research Institute[18] which summarizes the costs for several sized interim storage facilities including licensing, construction, operations and decommissioning in 2009 dollars. For the purpose of this study we will assume an ISFSI of 40,000 MTHM. The results of this evaluation are shown on Table 4. This study assumes that Dual Purpose Canisters (DPC) will be used which hold 10 MTHM.

Key assumptions in the EPRI analyses are that the construction of the ISFSI can be completed in 6 years without litigation. EPRI also assumes that only two casks per dedicated train are shipped in an annual campaign of 2,000 MTU. This assumption drives a need for a relatively high number of locomotives and rail infrastructure such as cask rail cars, buffer cars, etc. The other key assumption EPRI makes is that the DOE will provide the DPCs or Transportation, Aging and Disposal (TAD) casks to the utilities as well as storage overpacks. This assumption is not made by PFS since they are assuming that the utility will have already purchased the DPCs and overpacks will be shipped with the spent fuel casks on the same train saving approximately $250 million/year.

Table 4: EPRI Cost Estimate for Centralized Interim Storage

Cost of An Interim Spent Fuel Storage Facility[2]
40,000 MTHM (40 Year Operating Period)

Pre-Licensing Submittal Phase	$ 18.1 Million
Preliminary Design	
Environmental Report	
License Application Review Phase	$ 40. 3 Million
NRC fees	
Legal support for hearings	
Detailed design for facility	
Detailed design for transportation	
Environmental Impact Statement	
Capital for Construction (Overnight)	$ 136.9 Million
Construction Pre-Op Phase	
Storage pads	
Fuel Handling Facilities	
Security	
Capital Cost for Central Interim Storage Installation	**$ 195.3 Million**
Transportation Infrastructure	$ 176.5 Million
Locomotives (14)	
Rail cars (buffer, escort)	
Rail spur	
For 2000 MTU/yr	
DPC Canister Transfer & Transport Casks (28)	$ 189.3 Million
Capital Cost for Transportation Infrastructure	**$ 365.8 Million**
TOTAL CAPITAL COST (2009 $)	**$ 561.1 Million**
Annual Operating Costs	**$ 289.4 Million**
Administrative ($3.2M)	
Dual Purpose Canisters ($ 192.9M)	
Storage Ozverpacks ($ 52M)	
Freight + Other Fees ($ 41.3M)	
Annual Operating Cost Labor	
During Loading/Unloading	$ 8.0 Million
During Caretaker Period	$ 3.7 (Decommissioned sites @ $ 8 M)
During Loading/Unloading final	$ 8.5
Decommissioning	$ 225 Million

2 EPRI costs include a 30% contingency

These costs should be considered representative. The unfortunate aspect of these estimates is that they do not include delays and litigation expenses as experienced by the Private Fuel Storage company. The delays caused by opposition and litigation exceeded 10 years and legal and licensing fees amounted to over $70 million to date. As mentioned above, the PFS has an NRC license but is presently being blocked by federal agencies, which is being appealed in courts.

Shown on Table 5 is a current estimate[8] made by the Private Fuel Storage company based on their detailed design and cost estimates provided by vendors of the rail and construction companies for the ISFSI facilities for a government operated facility (no taxes and host fees). Additionally, the cost of the dual-purpose canisters and storage systems are not included which would account for a major portion of the difference between the EPRI and PFS estimates. Additionally, the PFS estimate does not include a contingency and only assumes that will need two dedicated trains to ship 2000 MTU using 3 casks per train.

Table 5: Private Fuel Storage Cost Estimate for an ISFSI[3]

For 40,000 MTU Facility – At 2000 MTU/year

(In 2009 Dollars)

Capital Cost for ISFSI Construction and Handling Facilities	$ 118 Million
Transportation Infrastructure Rail Cars, etc.	$ 53.2 Million
Rail Spur to Site	$ 34 Million
Annual ISFSI Operating Expense	$ 8.8 Million
Cost for Rail Transport (Dedicated Trains)	$ 75/mile

As can be seen, both estimates differ considerably on capital and operating costs. Reconciliation of these numbers with EPRI cost assumptions is difficult but some obvious differences are that EPRI assumes only two casks per train and a site that has considerably higher capital cost for construction compared to what PFS expects. It should be noted that the NRC reviewed the PFS estimates in their environmental report and was satisfied with the integrity of their numbers.

2.2 At Reactor Spent Fuel Storage Costs

The cost of at reactor storage per site is considerably less than the estimates for centralized interim storage. Informal estimates for the construction of an onsite ISFSI range from $35 to $50 million including the pad and additional security systems which should be compared to the capital costs of construction and licensing costs noted above at $195 million for a considerably larger facility. The costs of DPCs and cask handling equipment would be similar as would the storage

3 No identified contingency

overpacks. The annual operating costs should also be considerably lower for the at-reactor option since much of the onsite infrastructure including security is a marginal cost of operations. It is estimated that onsite operating costs while the reactor is operating is on the order of $1 million/year. When decommissioned, the annual operating costs are about $8 million per year for simply the caretaker role which includes taxes, insurance, security, NRC fees, etc.

2.3 Comparison of Centralized vs. At-Reactor Storage

The basic question in terms of economics is whether it is cheaper for the government to build a central interim storage facility or leave it at the reactors. The total capital cost of interim dry cask storage at the 45 nuclear plants when combined totals $1.6 Billion (at $35 million per ISFSI). Ultimately, this cost as well as the ongoing cost of operations will be paid by the taxpayer due to the failure of DOE to begin to take spent fuel in 1998. As more utilities are running out of spent fuel storage space in their spent fuel pools and construct ISFSI's, they become "sunk" costs to the government. Thus, given that the government has "already paid" or will pay for the capital cost of ISFSIs, is it still economic to build a central interim storage facility? This analysis will turn on the balance between what the government will have to pay utilities for storage versus what it will cost them to build a new facility and transport the spent fuel to the central storage site and how long that will take. The annual operating costs for spent fuel storage at an operating site are assumed to be $1 million per year. At 45 existing ISFSI sites, this translates to an annual operating expense of $ 45 million which is compared to a caretaker expense of a centralized ISFSI of $3.7 million.

The economic analysis assumes that the capital cost of the ISFSI's at reactors will have to be paid for by the government and the decision to build a centralized ISFSI will be based on the ongoing costs of operating existing ISFSI's, and how long before the DOE will begin taking spent fuel from operating and decommissioned sites. Based on President Obama's decision to take Yucca Mountain "off the table", interim storage will likely last for at least 15 to 20 more years even if the policy decision is made to recycle spent fuel. For decommissioned sites, this question is more pressing since the cost of monitoring is about $8 million per year per site. There are 9 decommissioned sites which will result in an annual operating cost to the government of $72million. Thus, the total annual expense for storage for all ISFSIs, not including sunk capital, is about $117 million per year which if extended for 20 years amounts to an additional $2.5 Billion, which would compare to a centralized IFSI caretaker cost of $74 million.

According to EPRI estimates, if a centralized facility were built at a cost of $561 million, which includes the needed transportation infrastructure, and spent fuel is removed at the maximum annual rate of 2000 MTHM the annual transportation cost, which includes the casks and loading and unloading at the ISFSI of $297 million per year for 20 years, this totals an expenditure of (561 + 20x297) for the same time period $6.5 Billion. In the 20 years approximately 40,000 MTHM would be shipped, filling the EPRI-sized storage facility. The savings to the government would amount to the savings associated with not having to pay for storage costs on existing ISFSIs which would include not only the O&M costs but also the costs expended by the utilities for the casks themselves at $750,000 apiece. The cost of reactor ISFSI's would still have to be paid to the utilities. Thus the offset cost to justify the central interim storage site would be limited to the cost of the monitoring of the ISFSI which is estimated to be about 45 million per year (45 operating reactor sites at $ 1 million/year) for about a 20-year delay in opening either a repository or a reprocessing plant which amounts to $900 million. Clearly the $900 million savings does not compare well with the $6.5 Billion in current dollars needed to build and operate an interim storage facility.

The General Accounting Office (GAO) completed an assessment of nuclear waste management options in a November 2009 report entitled " Nuclear Waste Management – Key Attributes, Challenges and Costs for Yucca Mountain Repository and Two Potential Alternatives"[19]. In this report, they perform a Monte Carlo calculation of expected costs of on-site and centralized spent fuel storage for durations of 100 years. They also include the cost of storage with repackaging of spent fuel for up to 500 years. The results of their analyses for 70,000 MT of spent fuel are shown on Table 6 below.

Table 6 Projections of Used Fuel Locations

Estimated Cost of Spent Fuel Storage for 100 Years
NPV in 2009 $ Billions from 2009 – 2018 for 70,000 MT

Storage Option	Estimated Range
At Reactor Site Storage	$ 10 - $ 26 Billion
Centralized Storage	$ 12 - $ 20 Billion
Permanent Repository	$ 27 - $ 39 Billion[4]

What this table shows that either at reactor storage or centralized storage for 100 years adds significantly to the cost of nuclear waste management due to the lack of a repository.

2.4 Transportation Costs

The EPRI assumptions regarding the cost of transportation assume that each train moves two DPCs per shipment, a low number compared to DOE's Yucca Mountain assumption of 11 casks per train. EPRI assumes, as does DOE, dedicated trains which will cost $280,000 per rail shipment. This is simply a fee by the railroads since the rail cars would have been purchased by the interim storage facility operator. This average cost is assumed independent of the rail miles travelled. The EPRI cost model assumes 100 rail shipments per year. PFS, on the other hand, costs out dedicated train shipment at $75/mile for its customers assuming that the return trip of the transportation casks to the reactor sites is done by conventional rail.

4 Only going forward costs for a Yucca Mountain like repository

2.5 Licensing Timeline

Should a volunteer site be identified, EPRI estimates that the time to license a centralized ISFSI is 6 years. This is highly optimistic and should not be assumed in any planning basis due to likely opposition from the state or other federal agencies. The facilities are relatively simple in design and construction and have been built at 45 reactor sites so that is not believed to be a technological challenge. The challenges are building rail spurs and getting permission to ship spent fuel to the sites using our national rail network and developing the needed emergency planning along all shipping routes from reactors to the chosen sites. PFS was in the licensing process for 10 years which is a more realistic time line. Timing for legal challenges needs to be factored into all aspects of the interim storage facility construction, operation and transportation.

2.6 Lifetime of Dry Cask Storage Systems

One of the key questions for long term storage is the lifetime of the storage system elements which include the spent fuel and cladding, canisters, any overpacks and concrete shields surrounding the dry cask storage systems. A critical question is the degradation mechanism of the spent fuel during long term storage in the canisters since ultimately the spent fuel must be shipped to either a repository or reprocessing plants. The canisters containing spent fuel are filled with helium which is an inert gas which should prevent any degradation by oxidation. Heat is continually generated by the spent fuel although decreasing with time which becomes an advantage for both storage and disposal.

The Nuclear Regulatory Commission which reviews these questions for on site storage facilities, concluded that initial (up to) 20-year licenses for such surface storage systems would be adequate, with license extensions possible[20]. The initial licenses for two utilities expired in 2006; both utilities applied and received license extensions for an additional 40 years, bringing the total license duration to 60 years. A third utility is presently applying for dry storage license extension. In 1983, the NRC reviewed the design of the Monitored Retrievable Storage Facility reaching the conclusion that the storage period of 40 years is acceptable[21].

In 1990, NRC in its Waste Confidence Rulemaking[22] concluded that the safe storage of spent fuel in dry storage was acceptable for “at least 30 years” after removal from the spent fuel. In the most recent Waste Confidence Rulemaking underway[23] the NRC has concluded that when combined with storage in the spent fuel pool for a full license and renewal period of 60 years, spent fuel can be stored for an additional 40 years for at least a 100 year overall storage time.

In reviewing the technical basis for such findings, it appears that limited actual data is available to support such a finding and much of the conclusion is based on analysis of degradation mechanisms over time and decreasing temperature. While storage may be acceptable for such long durations, a consideration that needs further evaluation is whether the spent fuel can be safely transported and handled after such a long period of dry storage. The Electric Power Research Institute has conducted series of studies and published technical reports on the dry cask storage systems[24] [25] [26] [27] [28]. They also participated in an inspection of a spent fuel assembly with a burnup of 35,000 MWD/MT burnup after a dry storage period of 15 years. The results of this inspection generally found that the spent fuel was in good condition but with some evidence of zirconium clad hydriding that could cause future embrittlement. Higher burnup fuels now more typically discharged have not been examined. In 1998, EPRI reached certain conclusions[29] concerning the feasibility of extending dry storage of spent fuel for 100 years:

- During normal storage after 20 years, the lower radiation fields and temperatures of 100-125 C favor acceptable fuel behavior for extended storage.
- Fuel cladding and oxidation degradation would occur early in life when temperatures are high and that the potential for off-normal and accident events would be the same during any part of the storage cycle.
- Domestic and international experience in dry storage provided confidence that spent fuel can be dry stored for beyond 20 years.
- EPRI concludes that the results of their analysis and data reviews suggest that concerns do not lie with the spent fuel assembly behavior for fuel assemblies with burnups of less than 50,000 MWd/MTU for long term storage up to 100 years.

For fuel currently being discharged by utilities, the burnup typically is higher than 50,000 MWd/MTU which have not been examined after periods of dry storage. EPRI identified the following concerns regarding long term storage for such fuels:

- The effect of higher fission gas inventory
- Rim effect on oxidation
- Effects of more hydrids in the cladding
- Larger oxide layers on the cladding

EPRI suggests that it will be important to establish a maximum storage temperature for high burnup fuels and the behavior of cladding under dry storage conditions. EPRI also developed a list of data needs for dry cask storage systems:

- To determine whether diffusion controlled cavity growth is viable in zircaloy cladding
- To determine temperature limits, cladding degradation mechanisms and post irradiation mechanical properties of new high burnup claddings and fuels.

In 2002 EPRI published a report which documented the results of their fuel inspection of a metal CASTOR cask which contained spent fuel (35,000 MWd/MTU) which was stored for 15 years. The results show:

- The gas analysis did not show any signs of cladding failure
- Visual examination of the cask lid O-rings indicated that they were able to maintain their seal function.
- Visual examination of the fuel did not show major crud spallation
- Visual examination showed that the condition of the spent fuel assembly looked like it did when it was first loaded 15 years ago in 1985.

EPRI also examined the fuel pellet and cladding which showed:

- Very small creep of the clad – less than 0.1 %
- Internal gas generation by the fuel within the cladding did not change during storage within measurement uncertainty.
- No hydriding or hydride reorientation was evidenced which could facilitate clad failure
- Little if any clad annealing occurred.

EPRI recommended that additional data be collected on the long term dry storage of spent fuel either in interim storage facilities or in the repository.

In its assessment of long term dry storage feasibility in ISFSIs with a focus on aging issues of spent fuel assemblies and corrosion of metals inside and outside the sealed spent fuel canister, radiation damage to metals and concrete degradation, EPRI concluded[23]:

- The aging issues of spent fuel and canister degradation had been adequately addressed or managed by the NRC in its issuance of 20-year ISFSI licenses with only a few issues that need to be reviewed.
- They conclude that surveillance and monitoring programs currently in use appear to be sufficient for extended storage – (these are largely limited to visual inspection and temperature monitoring with radiation monitors)

NRC bases a great deal of their decision about the lifetime of dry cask storage systems on a European Commission report in 1988[30] which concludes “present day technology allows wet or dry storage over very long periods and up to 100 years without undue danger to workers and the population”. The Commission however did not need to make such a finding in its September 18, 1990 Waste Confidence Rulemaking[31]. The bases of these decisions were some experimental evidence and very slow degradation mechanisms according to staff analyses. NRC also judges that the degradation mechanisms would be slow and that should a problem occur, remedial actions could be taken since the releases, if any, would be slow and easily detectable.

One of the key principles of long term storage is monitoring of dry cask performance to assure that no cask failures occur and if they occur, they can be corrected on a timely basis. This concept leads to the term “managed long term storage”.

The overall viability of long term storage, 100 years and beyond, depends on the ability of the canister system to prevent the ingress of air into the waste package. If the helium cover gas is maintained during the period of thermal decay, the spent fuel in the canisters will remain structurally sound for ultimate shipment to either a reprocessing plant or a repository in the future. Thus, the environmental conditions in which the waste canisters are located are very important in terms of corrosion degradation mechanisms. For example, in marine environments the presence of chlorides could degrade the canisters over time[32]. Inspection of waste canisters is not now planned to assess whether the canisters are experiencing any degradation either in the welds or metal. Additionally, high burnup fuels have not been examined to provide a basis for assuring that their degradation behavior is similar to that of lower burnup fuels.

In terms of overpack shielding, most of which is concrete based, normal external inspections can detect degradation and since their only major function is shielding, they can be repaired as needed.

As it appears that long term spent fuel storage will be required in any future scenario, provisions should be made to conduct routine inspections of the canisters to assure that air ingress is prevented and a means to transfer fuel to new canisters should failures occur. NRC will likely require additional confirmation of the shipability of spent fuel canisters after periods of long term storage to assure that the spent fuel will not be damaged during transport.

2.7 Transportation

Shipment of spent fuel poses yet another problem. Although this is routinely done for Navy and DOE spent fuel without significant incidents, the volume of commercial spent fuel is larger. The Department of Energy has been working with states and regional authorities to prepare for the shipment of spent fuel to the Yucca Mountain site. The Environmental Impact Statement for Yucca Mountain has identified possible rail routes for spent fuel coming from existing sites (

Figure 10). Unfortunately the current administration has stopped funding this effort which makes it difficult to assess the viability of any regional storage site given concerns about the transportation of nuclear waste. The experience of the Private Fuel Storage initiative in this area is not encouraging. Before spent fuel is shipped, emergency plans need to be put in place along all routes to include states and local communities. Additionally specially designed locomotives and rolling stock need to be qualified for shipment. PFS has pioneered the design and testing of locomotives but has been stymied by the lack of approval of a rail link to the main line. Many sites do not have access to rail which will require a heavy load trip shipment to the nearest rail line.

2.8 Legal Obstacles to Siting Interim Storage Facilities

The Nuclear Waste Policy Act of 1987 greatly limits the ability of the Department of Energy to proceed with regional interim storage even assuming that a volunteer site or sites can be identified. According to the Act, no license application for an interim storage site can be submitted until a construction permit is issued for Yucca Mountain and no fuel can be shipped to an interim storage facility until Yucca Mountain opens. The Act also prohibits siting of an interim storage facility in Nevada. Progress on any interim storage solution will require amending the NWPA to allow the DOE to build such a facility.

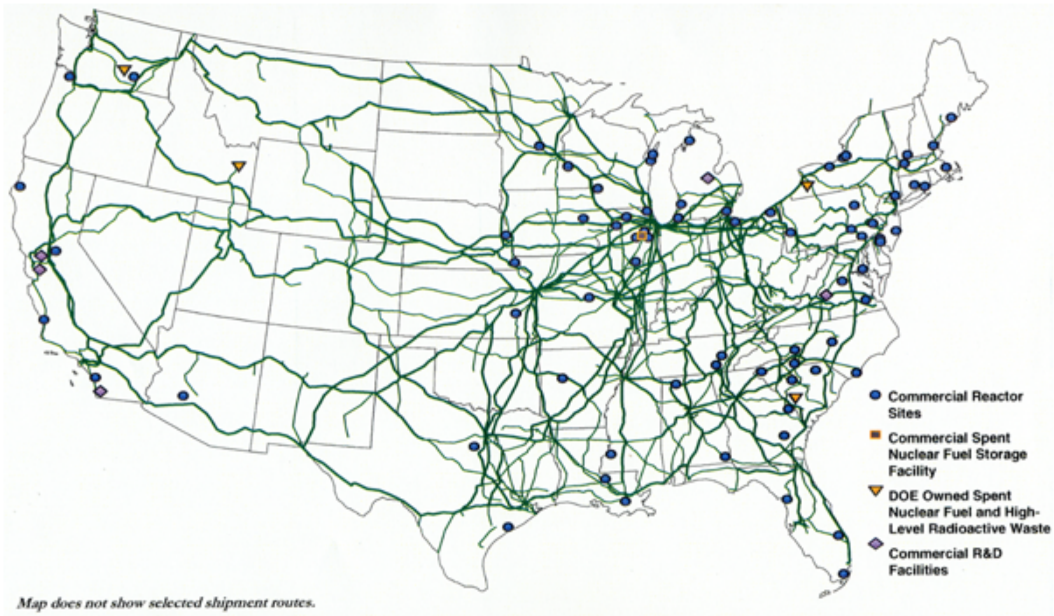


Figure 10: National Rail Routes

2.9 An Alternative Storage Option

As the nation begins to reassess all fuel cycle options and as the NRC licensing process for Yucca Mountain continues, an option should be considered that appears to be viable assuming that Yucca Mountain is shown to be a suitable repository site. In order to maintain future flexibility and allowing for an orderly decision process, an alternative option would be to load Yucca Mountain with spent fuel in a truly retrievable form. If the national decision is to reprocess spent fuel, the spent fuel in the mountain can be retrieved and shipped to a reprocessing plant (or such a plant could be ideally co-located with the repository). Should the decision be not to reprocess, the spent fuel could be permanently left there as currently mandated by the NWPA in Yucca Mountain. In either case, all options remain open. This strategy could potentially avoid multiple shipments of spent fuel should the no reprocessing option be chosen and if it is chosen, the number of shipments would be the same as in other regional storage options. The security value of storing spent fuel underground in a secure location (the Nevada Test Site) is also an important consideration. *Should the waste policy act be amended, consideration should be given to using Yucca Mountain as an interim underground storage facility that would be fully retrievable.*

Figure 11: Maine Yankee ISFSI - Plant Gone

2.10 Decommissioned Sites

An issue that needs to be addressed earlier is the spent fuel that is currently stored at decommissioned sites. These are sites at which the reactor plant is gone leaving only a storage pad and security guarding the spent fuel. Shown on Figure 11 is the Maine Yankee ISFSI in Wiscasett Maine containing 63 storage casks that represent all the high level waste generated after 25 years of operation. The plant is gone leaving only this legacy to government failure in finding a solution to high level nuclear waste management. Annual cost for such storage is about $8 million per year. It appears that DOE needs a nearer term solution for decommissioned sites since these costs are much higher than the marginal costs associated with storage at existing operating reactors which is about $1 million/year. Another reason for removal of these last vestiges of nuclear plant operation is that it completes the life cycle of nuclear power allowing the site to be developed for other productive uses.

2.11 Summary of DOE Options

Thus, the options for DOE are continue to pay the utilities to store at their reactor sites; build new green field regional storage sites and pay for the transportation costs; use an existing government facility such as an abandoned military base or DOE site which has the needed infrastructure such as a national laboratory; the Private Fuel Storage site in Utah or at Yucca Mountain. Of these options, the nearest term solution could be a national laboratory site. These are already regionally distributed as shown on Figure 12. It is quite clear based on past experience with shipping spent fuel to the Savannah River Site and other shipments to other national laboratory locations that public opposition can be expected, which could delay and possibly block any shipment of commercial spent fuel. The politics and public acceptance of the siting of interim storage facilities will be made much more difficult if there is no identified site for permanent disposal.

2.12 Successful Siting Example

Despite the difficulties in the US in siting interim storage facilities, there is a successful example of siting a repository in Sweden where two towns, Oskarshamn and Osthammar competed for the opportunity to host a repository. The lessons learned in Sweden might be useful for the US. Each town had within its confines existing well operated nuclear plants which meant that there was experience with nuclear issues. The nation made a commitment to solve the nuclear waste problem and supported the process of volunteer siting. The agency charged with finding a site and building the repository was a private corporation (SKB) consisting of the utility companies that operate Sweden's nuclear plants. The process of seeking a volunteer site was transparent and based on the science which was used to select the best site. Each town in the competition was offered an incentive to participate in the study with the "losing" town receiving 75% of the incentive fund of 162 million pounds. Ultimately SKB chose the Osthammar site for development. There was a 10 year public information program which ultimately resulted in strong public support in the community for the project based on potential jobs, trust in the process of scientific integrity and as importantly a recognition of the societal responsibility to address the problem in this generation and not leaving it to future generations[33].

This encouraging example may help the US in siting a regional storage facility.

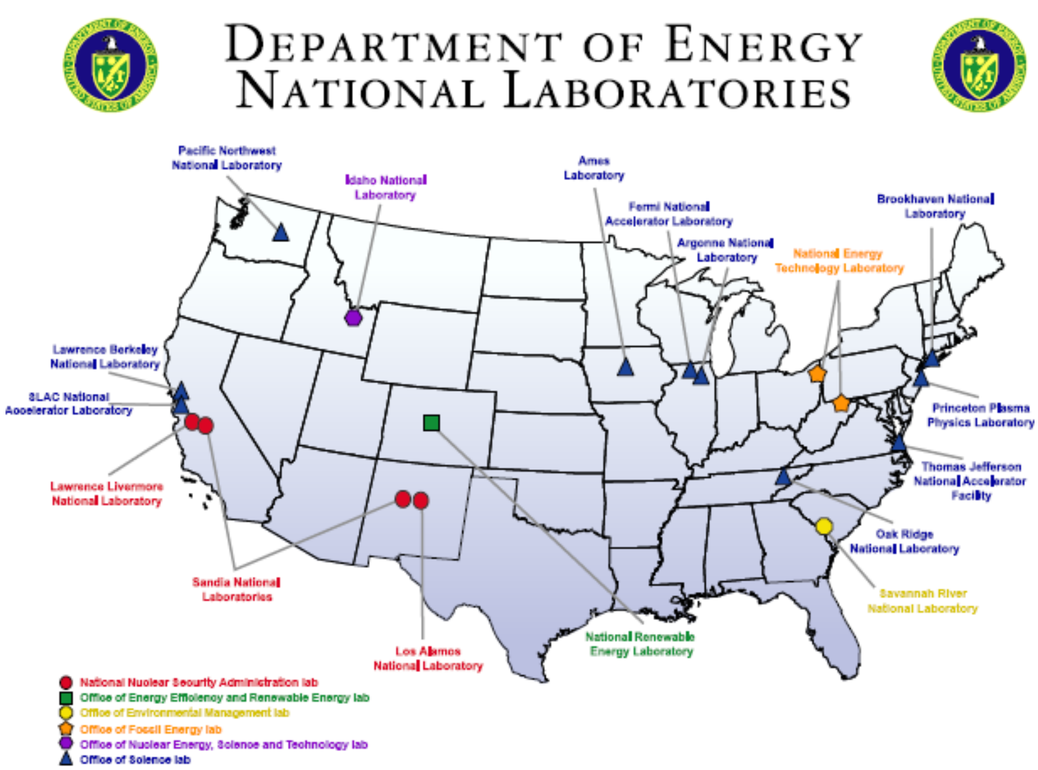


Figure 12: US National Laboratories - Not all are capable of Spent Fuel Storage

3.0 COMPARATIVE ECONOMIC ANALYSIS

While economic evaluations will not, at the end of the day, be the sole consideration of policy makers, a statement of the economic trade-offs present between alternatives will serve not only to inform the policy process, but also to motivate it. This analysis aims to provide an estimate of interim storage costs that is transparent to policy makers, focuses on country-wide gains and losses rather than those of any individual constituency, and provides a relative, assessment of the cost differences between alternatives. An economic model was developed to allow for ease of assessment of the variables and alternative scenarios including transportation to potential storage locations.

3.1 Explanation of the Model

There are three major cost centers to consider in evaluating interim storage alternatives: Facility capital costs, operations and maintenance, and transportation. Casking costs (placing spent fuel into transportable storage containers - DPCs), though significant, are not given consideration because they do not constitute an opportunity cost— all interim options require casking of SNF.

We analyze two major categories of interim strategy: continued at-reactor storage of SNF, and the creation of a single, centralized federal installation beginning operation in 2015. In making this assumption we are overly optimistic in the ability to open a new centralized storage facility by this year. It is important to note that there are other options available, including multiple centralized installations or consolidation of waste onto reactor sites with active operations. We will comment on these unanalyzed alternatives and the benefits or disadvantages they would create, but not estimate their costs with the same level of rigor as the at-reactor and single central installation options.

The options are evaluated under a range of conditions. First, we consider three different site locations, including western, Midwestern, and south-eastern candidates. Then we use a 7% discount rate in the analyses. Next, reflecting the significant uncertainty on our transportation cost estimates, we see how our results vary using three different transportation cost assumptions. Finally, we consider three different possible resolutions of the long-term waste management debate that involve the beginning of transportation of the interim-stored SNF in 2024, 2033, and post-2033 to either Yucca Mountain or a reprocessing plant. As a place-holder, Yucca Mountain is assumed to be the final destination in all three scenarios.

The model assumes two different transportation scenarios – normal freight and dedicated trains. While is it not expected that normal freight will be used, it is instructive to understand the differences in costs. The model follows a very simple logic in determining waste acceptance schedules: in the scenarios using normal transport, it ships waste from any decommissioned sites, and does not ship any waste from active sites. In the scenarios using dedicated transport, it ships waste from decommissioned sites by order of fewest MTHM-miles needed to completely clear the site. This is done to eliminate the annual operating cost that would need to be paid to the utility by the government reducing its liability.

In a given year, if there are no decommissioned sites remaining, it calculates whether it would be economical to ship waste from any active sites by comparing the present-discounted costs of shipping the waste twice (once to the central facility in the current year and once again to a repository in Yucca Mountain on the assumed year of its opening). It orders sites on the basis of opportunity cost per MTHM-mile, and then ships waste (up to the dedicated shipping capacity) from sites with the greatest net gain per MTHM-mile. If, in a given year, there are no sites from which it would be advantageous to consolidate SNF, then SNF shipments from previous years are delayed until capacity for that year is filled. This is done in order to reduce the net present discounted cost of shipment. If there are no sites from which it would be advantageous to consolidate fuel, and no SNF shipments occurred in previous years, then no transportation is scheduled for that year and the paid for capacity sits idle.

One difficulty with the transportation model is that it has not been integrated with the model that predicts waste discharges from active sites, so the estimation of how much SNF is available for transport from a given site is left to the discretion of the operator. While the total amount of SNF at a site in a given year can be easily obtained from the fuel discharge model, the total amount of SNF at that site *which has been casked* is unknown. In the transport scenarios, a re-transportation cost was included on the assumed year of long-term repository acceptance of waste. For the central installation option, this cost is equal to the transportation cost of shipping the entire inventory of the central installation to the coordinates of Yucca Mountain. For the at-reactor option, this cost is equal to the transportation cost of shipping all of the waste that had been shipped under the central installation option from its reactor of origin to the coordinates of Yucca Mountain.

3.2 Capital Costs

Capital costs are the simplest center to analyze. Because nearly all sites are expected to have completed construction of an ISFSI before a centralized facility could begin operation, there are no capital-induced opportunity costs for the at-reactor status quo option. We estimate the one-time facility costs of a central installation to be the Private Fuel Storage capital cost number of $118 Million for a 40,000 MTU facility. Significant portions of the capital cost go to licensing, administrative buildings, and other components that do not vary with the scale of the facility. Cost components that do scale with facility size, such as the cost of the concrete foundation that casks are placed upon, are relatively minor.

In our optimization model, which calculates the economic value of shipping spent fuel to a centralized facility, prior to 2034, a central interim facility would only need to store roughly 2,800 MTHM from decommissioned units. To be conservative, we shall assume that the full 40,000 MTHM will be ultimately needed in our model. Increasing the storage capacity of the central installation may reduce the need for increases in capacity at reactor sites and thus additional capital costs may be offset by foregone costs for utilities. This model assumes an overall cost optimization given the reality of utilities already building and operating ISFSIs. The model does not assume that the DOE will be paying utilities for onsite storage in addition to the cost of the centralized interim facility. This will change the economic result and value proposition for a large centralized facility.

3.3 Operations and Maintenance Costs

Operations and maintenance is a somewhat more complicated cost center. Several estimates, drawn from utility experience, suggest that the marginal cost of operating an ISFSI without an active reactor on site is $8 million per year. In our analysis, we have assumed this number. Additional costs in early years of operation for cask handling would need to be included for a more rigorous analysis.

There are two important comments to be made here. The first is that there are also costs to operating an ISFSI at a site with an active reactor - utility experience suggests these costs are in the area of $1 million per year. If this estimate is accurate, there is the potential that consolidation of waste from active sites may yield some net economic benefits, depending upon transportation costs. In situations where a fixed transportation cost is already paid for (i.e. dedicated transportation) the decision to consolidate waste from active sites is even more attractive, although the decision to consolidate waste from these sites still depends strongly on the distance between the central installation and the assumed variable costs of transport.

In our scenarios, we assume that the central facility O&M costs will be comparable to those of decommissioned sites. We make this assumption because we have found no compelling difference in circumstances between off-site central storage and storage at decommissioned sites. The needs for security, monitoring, and other services are similar across sites, and largely insensitive to facility size. Although actual experience may ultimately disprove this assumption, *a priori* there is no reason to suspect that costs would be significantly different except during initial cask acceptance.

3.4 Transportation Costs

Transportation costs are the most difficult cost center to analyze, in part because of the computational difficulty in determining waste acceptance schedules, but more importantly because of the scarcity of reliable estimates of transportation costs on a per mile or per MTHM basis. Included in the transportation costs are the costs associated with loading and unloading the DPCs onto the railcar at the reactor and unloading at the central facility. We do not include the cost of the DPC's or the initial filling of the DPCs with spent fuel since in this analysis, these costs would need to be incurred in both at reactor and interim storage sites. We have conducted our analysis with three different transportation cost assumptions, representing low cost, medium cost, and high cost scenarios. The low cost scenario uses a transportation cost of $4,000 per MTHM for loading and unloading the casks at the reactor site and at the central storage facility. This number is calculated from the EPRI $ 8 Million per year annual operating cost for the ISFSI.

Additionally there are fixed capital costs for the railroad cars and infrastructure for shipping (fixed cost) and a labor or variable cost associated with shipments on a per mile basis. When the

PFS value of $ 53.2 million for rail stock and rail spur costs of $ 34 million are included (depreciated at 10% per year) with an assumption that the average miles shipped to and from an interim storage site is 3000 miles for 2000 MTHM per year for a 3 cask train of 10 MTU per cask, a resulting capital transportation cost is $0.043 per MTHM-mile for each year. For the variable operating costs, using the PFS $ 75/mile fee for 3000 miles (round trip) for 67 – 3 cask trains, the total annual cost would be $ 16 million which includes $ 1 million in state fees for a labor cost of $ 0.04 per MTHM-mile. Thus the total transportation costs would be $ 0.083 /MTHM-mile.

If EPRI numbers were used, these costs would go up to:

Capital: $ 195 M
Rail Transportation Fixed: $ 365 = $ 0.122/MTHM-mile
Rail Transportation Variable (only two casks per train) = $ 0.075/MTHM-Mile
Total Transportation: $ 0.197/ MTHM-mile

Due to uncertainties in these estimates and assumptions of numbers of rail casks and trains needed as well as overall costs, several alternative scenarios were analyzed. The medium cost scenario uses a transportation cost of $ 8,000 per MTHM plus $ 0.20 per MTHM-mile. This scenario corresponds to our original estimation of capital and labor costs, but with an assumed increase due to licensing, security, monitoring, and the potential need for cranes or procurement of other specialized equipment in the loading process.

The high cost scenario uses a transportation cost of $25,000 per MTHM plus $ 0.30 per MTHM-mile. This scenario corresponds to a truck-heavy mix of transportation.

The distance between sites is calculated by taking the points of latitude and longitude of each site and finding the length of the shortest great circle arc between them, assuming the radius of the earth is 3659 miles. To account for variations in altitude and crookedness of path, this distance is multiplied by a scaling factor of 1.4.

It should be noted that this is a conservative estimate in comparison with the freight rail industry as a whole. In 2006, Class-I railroads shipped 1.772 trillion ton-miles, using 23,732 locomotives and 475,415 freight cars at a cost of 2.84 *cents* per ton-mile.

3.5 Decommissioned Reactors

Currently, there are nine commercial sites in the U.S. with spent nuclear fuel but no active reactor. If the entire reactor fleet was to receive license extensions to 60-years, the next shutdown would not occur until 2029, and the first opportunity to completely clear the site of spent nuclear fuel would not be until 2034, after the last discharged fuel assemblies had been aged in wet storage for five years (

Figure 13).

There are two important ways in which the next earliest shutdown date could be pushed back: the NRC could extend the licenses of reactors an additional 10 or 20 years, beyond the 60 year lifetime, or new reactors could be built at existing sites. Because the majority of economic benefit from waste consolidation comes from removing waste from decommissioned sites, it is important to predict when reactor sites will go inactive. The effect of license extension is fairly straightforward— that of new reactor build is more complicated.

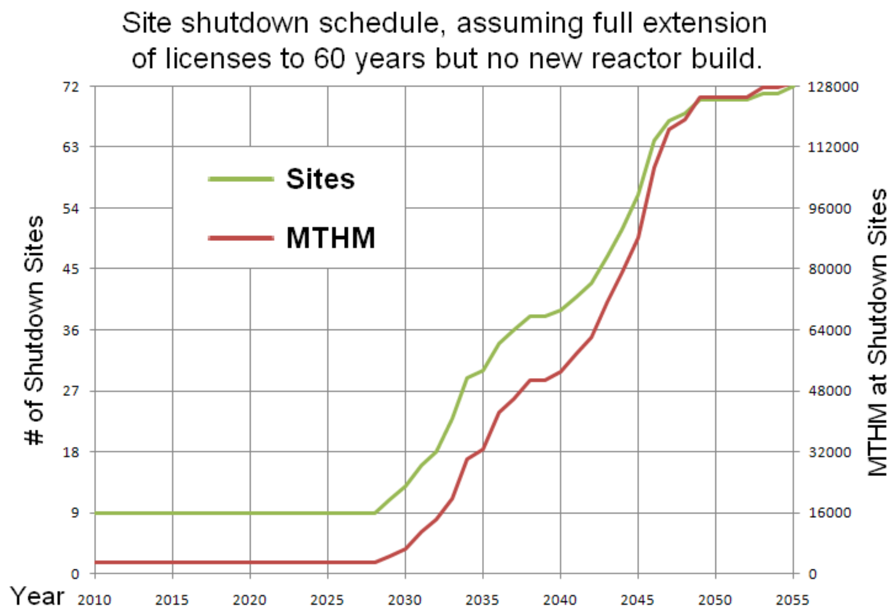


Figure 13: Shutdown Schedule of Operating Reactors with 60 Years of Operation

3.6 New Reactor Impact

As of writing, there are 32 reactor proposals engaged in some stage of the NRC licensing process. These 32 new reactors have been proposed at 21 sites, seven of which are green-field, and fourteen of which are existing active sites. The green-field sites are: Amarillo, Bellafonte, Blue Castle, Hammett, Levy County, Victoria County, and William Lee. The sites which have existing reactors (with the year that that site would otherwise shutdown in parentheses) are Turkey Point (2033), Calvert Cliffs (2036), North Anna (2040), Summer Unit (2042), Grand Gulf (2044), Callaway (2044), Susquehanna (2044), Enrico Fermi (2045), River Bend (2045), Nine Mile Point (2046), Harris (2046), South Texas (2048), Vogtle (2049), and Comanche Peak (2053). If all of these sites go through to construction, there will be no effect on the analysis until 2038, after which the impact is difficult to discern. Most of these reactors will have at least a 20 year spent fuel storage capacity in wet pools. Thus, the timeline for centralized interim storage is beyond the scope of this study.

On one hand, the construction of these new reactors will reduce the post-2038 O&M costs of the status quo option, but on the other, it is possible to make the argument that the capital costs of the status quo option will increase as a consequence of the new ISFSI licensing and construction that would be necessary under status quo, but avoidable with a central installation. The one-time licensing and construction of an at-reactor ISFSI is lower relative to that of an off-site installation (roughly $35 million compared to $118 million), but is comparable in present discounted terms to the $8 million per year costs of O&M at a decommissioned site.

In modeling the O&M cost center, we do not account for the benefits of consolidation until the year after the last waste package has been removed— in other words, there is a one year difference between when the transportation costs of consolidation are incurred and when the first reduction in O&M costs is seen. This introduces a degree of conservatism into the estimation of consolidation benefits.

3.7 Scenario Analysis

Three site locations were evaluated: the original Private Fuel Services site in Utah, the Savannah River site near the Georgia-South Carolina border, and the city of St. Louis, Missouri. These sites were selected as general representatives of three options: a western location near Yucca Mountain, an eastern location at a top candidate for reprocessing work, and a site in the Midwest which was close to the point in the United States with the lowest present-discounted transportation costs.

Three different end dates were evaluated as to when spent fuel can begin to be shipped either to a repository or a reprocessing plant: 2024, 2033, and the post-2034 period. 2034 is an important break point in the analysis because it is the first year when new decommissioned sites begin appearing. The post-2034 period does not receive the same level of rigor as the pre-2034 analysis, for two reasons: one, the computational difficulty of determining waste acceptance schedules for end dates after 2034 prevents dedicated transport scenarios from being rigorously evaluated, and the confidence in cost/benefit estimates of the post-2034 period is much lower, owing to the potential for license extensions and new reactor build. A more simplified method (which abstracts out much of the waste acceptance planning) was used to evaluate post-2034 gains using a 5% discount rate and varying transportation cost estimates.

Three different transportation cost assumptions were evaluated, as explained in the previous section on the transportation cost center. And finally, three different discount rates were evaluated: 3%, 5%, and 7%. Discount rates in the range of 4-6% are typical, reflecting generally accepted parameters on the economic growth rate, the marginal utility of income, and the preference of present consumption to future consumption.

3.8 Other Alternatives

Two scenarios which are not evaluated are multiple central installations and consolidation of SNF onto existing at-reactor ISFSIs. Building more than one facility would entail higher capital and O&M costs, but would reduce the average distance from a reactor site to the nearest installation, and thus reduce the transportation costs associated with consolidation of waste. Because of the relative size of the three cost centers, it can be inferred from this cursory analysis that a multiple facility approach would entail higher system-wide costs than a single-facility approach.

There are two advantages to the multi-facility approach that deserve mention. The first is that it may be politically easier to site multiple facilities rather than one. If waste were consolidated onto one site, local community may conclude that they are shouldering an unfair share of the waste burden. The second is that having multiple facilities would hedge the risk of consolidation of waste onto the wrong geographical location. The model we use assumes that after interim storage, the SNF is transported to Yucca Mountain for final disposal. This approach penalizes the creation of a central facility in the eastern United States because it assumes a larger transportation cost for these eastern sites. Conversely, if it was assumed that the SNF would be ultimately transported to a site such as Savannah River for reprocessing or other treatment, western sites would be penalized by higher transportation costs later in the system lifetime. Given the uncertainty surrounding the nation's long-term waste policy, policy makers may wish to create multiple sites, not only as a means of mitigating the policy risk, but also as a signal that interim policy decisions are not indicative of long-term policy decisions.

Consolidation of SNF onto existing reactor sites, from an economic perspective, appears to be a superior economic alternative to a single centralized facility by many metrics. By avoiding the creation of a new installation, this approach eliminates the capital cost of the central installation and averts the O&M costs associated with that facility. Transportation costs would be lower as well, as the distance between reactor sites is much less than the average distance between a central facility and a reactor. Also, it may be possible, using this consolidation approach, to begin operations sooner than would be possible with a centralized facility.

There are, however, some disadvantages associated with consolidation onto existing facilities. In the near term, pursuing this option would mean convincing not only the owners of roughly five to nine different reactor sites to accept waste transfers from decommissioned sites but also the local community and states — a difficult challenge given past experience. Furthermore, consolidation may jeopardize the political fortunes of new reactor build: it is logical to consolidate waste onto sites that will continue to have an active reactor for a long time, and the sites with the longest futures are those that have been most recently built.

3.9 Results

Our model found, on net, considerable economic benefits to consolidation of waste onto a central installation ***for decommissioned sites***. Table 7 shows a summary of the results obtained for non-dedicated transportation (regular freight) for the full range of scenario parameters for only the 7% discount rate. Only decommissioned sites were considered in this analysis. The values in each cell are the net present discounted difference in costs between at-reactor storage and central installation consolidation, in millions of dollars.

Table 7 : Present Value Analysis Results in Millions of Dollars

Between ARS and Centralized - $ 118 M ISFSI – Normal Freight
For Decommissioned Sites
(positive values favor centralized storage for decommissioned plants)

		Private Fuel Services, UT		St. Louis, MO		Savannah River Site, SC	
		2024	2033	2024	2033	2024	2033
$4,000/MTHM, 4.3c/MTHM-Mile	7%	279	506	279	506	279	279
$8,000/MTHM, 20c/MTHM-Mile	7%	267	494	267	494	267	494
$25,000/MTHM, 30c/MTHM-Mile	7%	219	445	219	219	219	445

Using the EPRI values for the ISFSI and transportation costs, the net present value of a centralized interim storage location decreases about 25 % but is still high. It is quite clear from this analysis that the location of the ISFSI is not important from a cost perspective giving the DOE great flexibility in siting. Cost savings for centralized storage in the post-2034 period were higher. This reflected two factors: the increasing number of inactive sites post-2034, and the general trend of increasing benefits as the length of the interim period increases.

Similar cost modeling was performed for dedicated transportation options as well. Table 8 shows the results for the PFS site, with values from the above table included for comparison. The shipping capacity is that which dedicated trains can ship per year. Two million ton miles equals 2000 MTU shipped to the Private Fuel Storage facility for an average distance from reactor sites. Active sites are included in the dedicated transport analysis by selecting certain reactors for the analysis based on age of spent fuel.

Table 8: Results for Dedicated Trains - Centralized vs. At Reactor Storage

For Both Decommissioned Sites and Some Operating Sites
For the PFS ISFSI Costing $ 118 M; (Millions of Dollars)

			2024	2033
2 million ton-mile capacity	$4,000/MTHM, 8.3c/MTHM-Mile	7%	245	476
	$8,000/MTHM, 20c/MTHM-Mile	7%	221	456
	$25,000/MTHM, 30c/MTHM-Mile	7%	120	375
5 million ton-mile capacity	$4,000/MTHM, 8.3c/MTHM-Mile	7%	253	483
	$8,000/MTHM, 20c/MTHM-Mile	7%	214	450
	$25,000/MTHM, 30c/MTHM-Mile	7%	279	312
Normal Transportation	$4,000/MTHM, 8.3c/MTHM-Mile	7%	279	506
	$8,000/MTHM, 20c/MTHM-Mile	7%	267	494
	$25,000/MTHM, 30c/MTHM-Mile	7%	219	445

Dedicated transport results in uniformly lower cost savings for the central installation option. This dedicated transport model determined that removal of spent fuel from operating sites was advantageous sites fully utililizing dedicated rail transportation infrastructure. The model did not assume any credit for reducing the at reactor ISFSI operations costs since it was assumed that the spent fuel in the spent fuel pool would be offloaded first.

The impact of the utility lawsuits on spent fuel removal complicates this analysis since the US government is obligated to pay for at reactor ISFSI's and their operating costs until such time as the DOE removes the spent fuel according to the acceptance rates stipulated in the contracts. Shown on Figure 14 are the costs associated with DOE delays in spent fuel acceptance. This figure shows that even if DOE begins taking spent fuel in 2017 the liability of the federal government will be $ 7 Billion. If they start taking spent fuel in 2020, that liability increases to $ 11 Billion. Clearly, the construction of an interim storage facility might lower this liability if DOE is able to build an interim storage facility or ship to Yucca Mountain earlier than 2017. Both are judged to be unlikely.

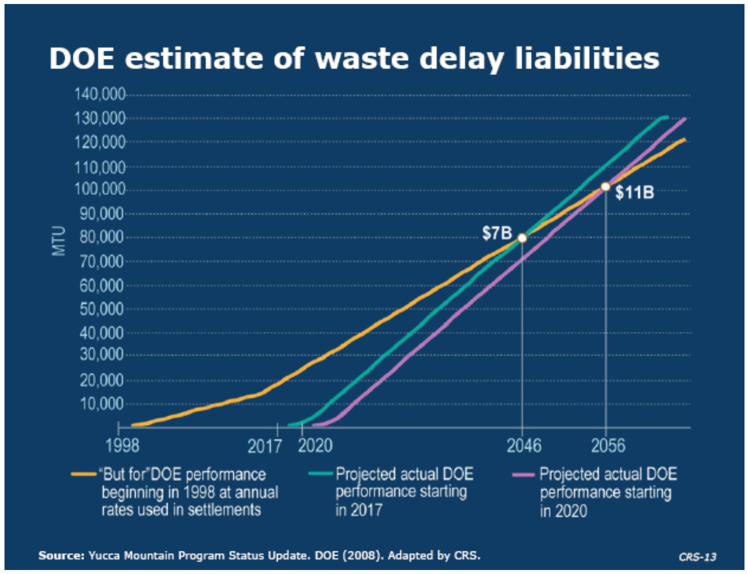


Figure 14: DOE Financial Obligation for Failure to Take Spent Fuel in 1998

Using the cost per MTHM as calculated by DOE on this figure of $ 87,500/MTHM which is an integrated cost of building and operating an ISFSI at reactor sites, the real value of beginning to remove fuel from sites, build new ISFSI's or avoid expansions of existing facilities can be simply estimated to be approximately (2000 MTHM x 87,500) $ 175 Million per year based on shipping 2000 MTHM. This overestimates the cost saving since the sunk costs of building the original ISFSI would have to be paid. The real savings would be on the order of saving the cost of loading and monitoring new casks at ISFSI's which is about $ 65 million per year ($ 1 million per year for operations and maintenance).

Thus, assuming that the DOE can site and build an ISFSI by 2017, purchase and qualify dedicated rail systems, put in place emergency plans along all rail routes, avoid lawsuits, the final tally for costs are shown on Table 9.

Table 9: Total DOE Obligations for Centralized Spent Fuel Storage Facility (Assuming PFS Costs)

Government Obligation to Utilities	$ 7,000 Million
ISFSI Construction	$ 118 Million
Railroad Infrastructure	$ 87 Million
Annual Operating ISFSI Expenses	$ 8 Million
Potential Savings per year[5] (assuming site is cleared of ISFSI)	$ 65 Million

5 Assumes a $1 million savings per year per ISFSI for 65 operating sites.

There does not seem to be a plausible way for the government to reduce the obligation to utilities for the sunk costs of at reactor ISFSIs until the sites are cleared of spent fuel. The utilities are not likely to do this since, by contract, they are permitted to ship spent fuel without designation from what location – dry storage or the spent fuel pool. The court may rule that the DOE will be free of the obligation regardless since the objective of the central ISFSI is to reduce the cost to the government. In either case, it will likely be years before all the spent fuel is removed from dry cask storage. Given these fixed and sunk costs, despite the analysis which shows that shipping to a centralized ISFSI is advantageous, the total cost to the government when considering the cost of building and operating an ISFSI means that they continue to pay for the cost of at-reactor storage. This is certainly true until such time that the government decides what the policy of the country will be regarding the fuel cycle – either direct disposal or recycling.

3.10 Economic Conclusions

The first important result to note is the nearly uniform result that a central installation outperforms at-reactor storage neglecting the government sunk costs for at-reactor ISFSIs for decommissioned sites. Even given a conservative set of parameters and assumptions (high transportation costs, no accounting of consolidation benefits from active sites, etc), the model still found large net-positive benefits to a central facility. The size of the gains also leads to the conclusion that even if not all decommissioned sites could be consolidated, the gains from consolidating just a small number of them are still substantial enough to justify a centralized facility. For example, at a 3% discount rate, and an interim period from 2015-2033, the avoided O&M costs of consolidating a single decommissioned site amount to $66 million dollars. Assuming low transportation costs and a favorable location, a central facility that consolidated a mere three sites could be a net benefit.

A second important result is the relative indifference of costs to site location despite the significant real distance between sites. This implies that policy makers should have wide flexibility in siting a central facility, a flexibility that should come in handy considering past experience.

Given the uncertainty of future nuclear energy policy in terms of recycling or direct disposal, interim storage should be considered as an integral part of the nation's waste management strategy and not necessarily as a failure of the US to open a geological repository. While a repository is needed in all scenarios for the disposal of nuclear waste, the issue of what is to be disposed is still unresolved. Should the design of Yucca Mountain be modified to make the spent fuel retrievable as a normal course of operation, it would allow more flexibility in the design of the US waste management system. Thus, the US could either build a central interim storage facility, use Yucca Mountain as an interim storage facility which could also be used as a repository or build several interim storage facilities to make the siting somewhat easier.

A final comment is that a higher degree of confidence is required in the accuracy of the cost parameters used for transportation costs and O&M costs at active sites before a definitive conclusion can be reached on dedicated transport or consolidation of waste from active sites. If transportation costs are sufficiently low, and O&M costs sufficiently high, it would be cost-advantageous to consolidate SNF from active sites. This would create a regular stream of SNF to be consolidated, and in turn improve the relative costs of dedicated transport. Our analysis supports this conclusion.

3.11 Non-Economic Factors

The economic considerations are not the only factors in determining whether a central interim storage site is needed. While there is much discussion of a "nuclear renaissance", there is a legitimate concern by the public, especially in communities that are being asked to host either a new nuclear plant or add additional nuclear capacity to an existing site about the future of the nuclear waste being generated at the site. Recently opponents to nuclear power have cited the lack of a repository as a contention in licensing proceedings as a reason for opposition to new nuclear plants. The NRC Atomic Safety and Licensing Board allowed a contention requiring a full adjudicatory hearing on the question of what is to happen to the nuclear waste produced at the Progress Energy's Levy County nuclear plant. Thus, there is a need to demonstrate that spent fuel can be removed from existing nuclear plant sites even though there is no decision with regard to the final disposal solution.

For decommissioned sites, the problem, while not affecting operations, is another example of federal policy failure to deal with an issue for over 60 years. Many of these plants are fully decommissioned with the only facility remaining on the site being the Independent Spent Fuel Storage Installation. Sound government policy would be to remove this waste to another centralized facility not only to reduce costs, but to demonstrate that nuclear plant sites can be completely decommissioned, restoring the sites to a greenfield for other uses.

One of the most important public concerns is the transportation of nuclear wastes. Despite an enviable record of safe transportation of nuclear materials, the public is wary of moving nuclear wastes along railroads and highways past populated areas. If decommissioned plant spent fuel is shipped to a regional facility, it can be a useful exercise to demonstrate that future shipments would pose little if any safety concern.

Some suggest that while the safety and security of spent fuel at operating sites is strong, the overall advantage of consolidating the spent fuel might be better in terms of potential terrorist targets. This must be counterbalanced by the exposure to terrorism of the spent fuel during shipment. This is a risk that must be faced in either scenario eventually however. We do not view the at reactor security as a major threat.

The swing question about whether the government should build a central ISFSI rests with the assumption of whether it will be obligated to pay utilities for damages for failure to take spent fuel. With the exception of the settlements reached with utilities, other claims have not been settled and are still to be resolved in the courts due to Department of Justice appeals. If these sunk costs are excluded, the economic argument suggests that building a central facility is the most prudent course of action.

4.0 CONCLUSIONS OF INTERIM WASTE STORAGE EVALUATION

The most significant finding is that regardless of the future of Yucca Mountain or a policy decision on the future of reprocessing and recycling, storage of spent nuclear fuel at reactor sites will continue for at least 15 to 20 years. This finding is based on the timing of a final decision on Yucca Mountain as determined by the Nuclear Regulatory Commission or Congress, the timing of making a national decision on recycling and its subsequent implementation and the timing associated with finding a site for an interim storage facility, its licensing and construction. Deciding to build an interim storage facility until these fundamental issues are resolved does not make economic or policy sense. *This finding also leads to the conclusion that interim storage of spent nuclear fuel must be an integral part of any national waste management strategy.*

The siting of a centralized regional interim storage facility will be more difficult than in the past due to a lack of an agreed-upon exit strategy for the spent fuel in storage. Past volunteer efforts authorized by Congress with the creation of the Nuclear Waste Negotiator to site a Monitored Retrievable Storage facility failed due in part to political opposition and congressional political interference in the process once decisions were near. There are no indications that there are any fundamental changes either in the politics of siting interim facilities or the willingness of states and local communities to accept such a facility. Some suggest that co-locating a reprocessing plant and an interim storage facility with its attractiveness of jobs and economic stimulus might be a differentiator today, but that remains to be seen.

The Nuclear Waste Policy Act, as Amended in 1987, severely restricts the Department of Energy from building an interim waste storage facility until Yucca Mountain obtains an operating license. This legislative restriction needs to be removed to allow the construction of such a facility independent of the progress on a repository site. Of course, this will make the siting of an "interim" facility more difficult. Private utility efforts at building a regional interim storage facility have also been stymied by national and state political opposition despite being granted a Nuclear Regulatory Commission license to build and operate such a facility after a 10-year licensing process.

Even if a volunteer site could be found, the licensing process could last 10 years with another 3 to 5 years for construction before spent fuel could be accepted by the facility. Also needed is the transportation infrastructure to ship the spent fuel casks to the facility, which could be done concurrently. This process could be expedited if existing federal facilities could be used, which have the requisite land, security and infrastructure to support interim storage. The Department of Energy operates many national laboratories across the country as does the military with its numerous bases. While the PFS site has many political difficulties, it should also be considered a near term option since it already has a Nuclear Regulatory Commission license.

There is a growing national taxpayer obligation to utilities for failure of the Department of Energy to remove spent fuel beginning in 1998 from nuclear plant sites according to contracts signed with the DOE. The costs are meant to cover the expenses utilities have incurred to build their own dry cask storage facilities at their sites. It is estimated that this obligation would total $11 Billion by 2020. By that time most of the utilities will have built their own Independent

Spent Fuel Storage Installations for which the government will have to pay under court decisions. These "sunk" costs affect the economics of building a central spent fuel storage facility since the marginal cost of operating an ISFSI while a nuclear plant is operating is relatively small. Thus, when the ongoing costs of paying utilities for at reactor storage are included as a sunk cost, these expenses plus those of building a centralized ISFSI and transporting spent fuel from operating sites is likely not to be economically justified since it does not reduce costs but adds to the costs of waste management. This is not true for sites that have been decommissioned leaving only the ISFSI in place with relatively high annual operating costs which the government (taxpayer) is also obligated to pay. By clearing these sites, the government obligation ceases.

Decommissioned plants have stranded spent fuel stored on cleared nuclear plant sites. Economic analyses suggest that removal of spent fuel from these sites would be advantageous to the taxpayer but the size of the centralized interim storage facility would be considerably smaller since the economics of removing spent fuel from operating sites is not shown to be economic since the government has already "paid", by court ruling, for the capital cost of the facility at the plant sites. Once a larger number of nuclear plants are decommissioned the incentive for a centralized facility increases as the costs of operating these independent facilities are higher than a centralized facility. It is expected that by 2030, there will be an economic need for a centralized interim storage facility assuming all reactors have their licenses extended to 60 years.

An option to address the decommissioned plants is to co-locate decommissioned spent fuel at an exiting decommissioned plant ISFSI in a community willing to host spent fuel from other plants. The chances of succeeding in this effort are unknown but depend on the willingness of the community and state to accept such a solution. This might be a first near term test of the concept of finding volunteer sites in a community that understands the real meaning of spent fuel storage and past nuclear operations.

Should this option not work, it is recommended that a small 3,000 MTHM interim storage site be built to accommodate decommissioned sites which could be expanded in the future should national policy continue to fail in terms of either moving forward with a repository or a reprocessing facility to accept spent fuel from future decommissioned sites. The location of this facility is quite flexible given that the transportation costs are relatively small.

The most recent capital cost estimate for a centralized ISFSI of 40,000 MTHM is about $560 Million which includes design, licensing, and construction of the storage pad, cask handling systems, and the rail infrastructure (locomotive, rail cars, transport casks, etc). Annual operating costs during loading are estimated to cost $ 290 million per year which includes the costs of the dual purpose canisters and storage overpacks. Fully loading this size ISFSI will take 20 years followed by a period of "unloading" and eventual decommissioning. The middle period of "caretaking" is estimated to cost about $4 million per year compared to caretaking decommissioned reactor costs for $8 million per year per site. The cost savings from consolidating the spent nuclear fuel from decommissioned sites is a compelling motivation for the federal government to create a centralized storage installation or facilitate transfers between decommissioned and active reactor sites.

The Private Fuel Storage company has updated its cost for a centralized facility in 2009 dollars to indicate that the cost of an ISFSI is $118 Million assuming it is run as a federal facility with no taxes paid. The cost of the rail infrastructure for the PFS includes transport casks, and all handling equipment is estimated to be $ 53 Million plus an additional rail extension to the site of $ 34 Million. Dedicated trains are assumed with 3 casks per train assumed in the analysis. Annual operating expenses for loading and unloading casks are approximately the same at $8.8 million. The PFS numbers do not include the costs of the waste canisters or storage overpacks which are assumed to be shipped to the site from the reactors.

The rail infrastructure costs are considerably different at $53.2 Million compared to EPRI's $366 million due largely to a smaller number of locomotives needed (4 vs. 14) and associated cask shipping cars for the same 2000 MTU per year of shipments to the interim storage site. PFS calculates the cost to ship 3 casks per train to be $75 per mile with dedicated trains. The PFS numbers shown reflect actual cost estimates for their project in Utah. Reconciliation of these numbers with EPRI cost assumptions is difficult but some obvious differences are that EPRI assumes only two casks per train and a site that has considerably higher capital cost for construction compared to what PFS expects.

Economic modeling of the net present value advantage comparing at reactor storage for decommissioned sites with centralized storage at a number of reference locations in the east, west and mid-west show significant advantages for consolidation at centralized sites. A second important result is the relative indifference of costs to site location despite the significant real distance between sites. This implies that policy makers have wide flexibility in siting a central facility, a flexibility that should come in handy considering past experience.

Given the uncertainty of future nuclear energy policy in terms of reprocessing or direct disposal, interim storage should be considered as an integral part of the nation's waste management strategy and not only as a failure of the US to open a geological repository. While a repository is needed in all scenarios for the disposal of nuclear waste, the issue of what is to be disposed is still unresolved. Should the design of a repository be modified to make the spent fuel retrievable as a normal course of operation, it would allow more flexibility in the design of the US waste management system. Thus, the US could either build a central interim storage facility, use Yucca Mountain (assuming it continues) as an interim storage facility which could also be used as a repository, or build several interim storage facilities to make the siting somewhat easier. The last option would be the most costly.

A higher degree of confidence is required in the accuracy of the cost parameters used for transportation costs and O&M costs at active sites. If transportation costs are sufficiently low, and O&M costs sufficiently high, it would be cost-advantageous to consolidate SNF from active sites. Our analysis preliminarily supports this finding. This would create a regular stream of SNF to be consolidated, and in turn improve the relative costs of dedicated transport. However, when the sunk costs of existing at reactor ISFSI's are included in the overall cost, it is cheaper to keep the spent fuel at the active reactor sites. The dedicated train scenarios do show that the use of dedicated trains can be advantageous in terms of lowering the overall cost of the management of spent fuel in interim storage from all sites since it more effectively utilizes the dedicated train capacity.

Strong non-economic arguments can be made for building an interim storage facility. These include addressing the public concern about new plant construction and associated long term nuclear waste storage at plant sites, demonstrating the spent fuel can be safely transported, setting the stage for ultimately clearing out all sites either to a reprocessing plant or a repository. These are in addition to addressing the stranded nuclear waste at fully decommissioned nuclear plants. All are seen as important public confidence building initiatives to support the continued use of nuclear energy.

With the possible long term storage of spent fuel approaching 100 years in a combination of wet and dry storage, the technical data supporting such timelines was reviewed. The Nuclear Regulatory Commission has determined that in combination of wet and dry storage periods approaching 100 years are possible based on degradation analysis and monitoring. However the actual data supporting such a conclusion is limited to a physical inspection of a low burnup fuel assembly after 15 years of dry storage. High burnup fuels currently used and that are in storage have not been inspected to determine whether their behavior in storage will be similar to low burnup spent fuel. Assuming that the integrity of the storage canisters is not breached allowing for air ingress, storage for long periods should be possible despite continuing degradation mechanisms due to the reduction over time of the temperature of the spent fuel. Presently, NRC licenses dry cask storage installations for 20 year but is now considering extending ISFSI licenses to 40 years.

While the technical justification of long term dry cask storage may be established, additional technical justification will be needed to assure that spent fuel integrity (suitable for subsequent handling and transport) are met and that the integrity of the canisters can be maintained. This may require confirmatory research involving spent fuel inspections of high burnup fuel in dry casks and more extensive degradation modeling to provide adequate justification for expected periods of storage of the order of 100 years or more.

In conclusion, based on the economic analysis and the uncertain policy decisions of the future, the best strategy is for utilities to store spent fuel at reactor sites until such time that the fate of Yucca Mountain has been established and/or a decision is made on the timing of reprocessing technologies and their application in the United States. The only exception to this conclusion is that for decommissioned sites. Once those decisions are made, and according to our model, the suggested alternative is to co-locate interim storage with the reprocessing facility to avoid additional transport charges as well as security risks associated with the transportation of spent fuel or reprocessed waste. It is our expectation that the technologies to implement reprocessing and fuel fabrication in the US for either recycling in light water reactors or use in fast reactors will not be available until 2030 to 2040 time frame. This means that the only reasonable option that will minimize taxpayer dollars is continued on-site storage at operating nuclear plants, which utilities will be capable of cost-effectively doing for the duration of their operating licenses.

For decommissioned plants, consolidating spent fuel makes economic and policy sense either at a national laboratory site, a new central interim storage facility of about 3,000 MTHM or at an existing plant that is currently storing spent fuel. All of these depend on the host town and state willing to accept this near term solution. This facility would provide the needed public confidence to demonstrate that spent fuel can be shipped from operating sites and safely stored at a interim location pending either reprocessing or disposal.

A final observation based on the history of the US nuclear waste policy is that due to the long time frames for development and deployment, a consistent, durable, and stable national policy is needed to successfully address the ultimate question of what are we, as a nation, going to do with nuclear waste.

Recommendations

Given this long term horizon, several recommendations are made:

1. Remove spent fuel from decommissioned reactor sites to an existing secure national facility that has the infrastructure to support long term storage. Should this not be possible, build a centralized interim storage facility capable of storing 3,000 MTHM of spent fuel from decommissioned reactors that could be expanded as needed when other operating reactor sites are decommissioned in the 2030 time frame.
2. If a policy decision is made on recycling, build a single interim storage facility at the proposed site of the nation's reprocessing and recycling plant. This would minimize future storage and transportation costs and minimize proliferation risks. Should the nation decide to transmute nuclear wastes, this facility could also be the location of a fast transmuter reactor.
3. To provide additional flexibility and greater certainty in the ultimate solution to the nuclear waste problem, redesign Yucca Mountain (or any future repository) for true retrievablility to allow for Yucca Mountain to become an underground retrievable storage facility should the policy decision on reprocessing be delayed. This would provide secure underground storage and if the decision is made not to reprocess, this site could become the final waste disposal solution. The only disadvantage is that it would require an additional transportation step to the reprocessing plant should the policy decision support such a path.
4. Should politics and lawsuits permit a faster solution, the DOE should acquire the already NRC licensed Private Fuel Storage site in Utah for an interim storage site. This would provide a quick and less costly solution to siting of an interim storage site; provide relief to utilities and ultimately the government on liabilities associated with failure to meet contractual obligations; and begin the demonstration of transportation of nuclear materials which will be needed in the future for the longer term options being considered. This solution would be especially valuable for clearing decommissioned sites, ending the government obligation to pay for contract defaults.
5. Introduce legislative to remove the linkage between the repository and the construction of an interim storage facility.
6. Conduct confirmatory research to increase confidence in the technical feasibility of long term dry cask storage to assure that after storage for a long time, the spent fuel can be safely transported to either a repository or reprocessing plant

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