Assessment of Texas's High Level Radioactive Waste Storage Options

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Texas Commission on Environmental Quality

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Acryonms and Abbreviatons

°F	Degree Fahrenheit
AEC	Atomic Energy Commission
BRC	Blue Ribbon Commission
CFR	Code of Federal Regulations
DOE	United States Department of Energy
DOI	United States Department of the Interior
DOT	United States Department of Transportation
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GEIS	Generic Environmental Impact Statement
GNEP	Global Nuclear Energy Partnership
HLW	High Level Waste
ISFSI	Independent Spent Fuel Storage Installation
MRS	Monitored Retrievable Storage
MTHM	Metric Ton Heavy Metal
MTU	Metric Ton Uranium
MW	Megawatt
MWd	Megawatt-day
NRC	Nuclear Regulatory Commission
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
PFS	Private Fuel Storage
SNF	Spent Nuclear Fuel
STP	South Texas Project
TAD	Transportation, Aging, and Disposal
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant

Background

Despite years of research and expense there is currently no federal disposal site for high level waste (HLW), which include spent nuclear fuel (SNF). Further, recent developments seem to imply that a federal solution is not immediately coming. Fortunately for Texans, the current practices for storage of HLW are environmentally sound. State and Federal regulations are adequate to protect the environment and public health. However, we know that most of the high level waste in storage is in the form of SNF and is stored at nuclear facilities which are within 100 miles of major metropolitan areas. Further, the continued availability of an appropriate storage area may prove challenging as the nuclear facilities face decommissioning at the end of their licenses.

The Texas Commission on Environmental Quality has been asked to make an assessment of the State's high level radioactive waste storage options and file a report with the Office of the Governor no later than March 1, 2014.

Executive Summary

Commercial nuclear power production began in December, 1957. For three decades afterwards, nuclear power plants were designed and built with the assumption that the used nuclear fuel, commonly called spent nuclear fuel (SNF), would be shipped to an off-site facility to be reprocessed and the resulting high level waste (HLW) disposed at a federal government operated and owned facility.

However, President Carter issued a presidential directive in 1977 that prohibited further commercial reprocessing. Even though President Reagan canceled this ban, as of yet the private sector has not attempted to build or license a commercial reprocessing facility since the one-time use fuel cycle is more economical.

With reprocessing of SNF not available, Congress passed The Nuclear Waste Policy Act (NWPA) of 1982, and amendment in 1987, to develop a geologic repository for the disposal of SNF. The NWPA established the Nuclear Waste Fund to be used only for funding SNF disposal and is financed by a fee of $1 per megawatt hour of nuclear power generated. The U.S. Department of Energy (DOE) entered into Standard Contracts with the commercial nuclear power plants in which the DOE would begin to take title to, transport, and dispose of the SNF by January 31, 1998.

The 1987 amendment stipulated that only the Yucca Mountain site was to be characterized for the geologic repository. Opposition by the State of Nevada and other groups delayed the characterization and licensing of the Yucca Mountain site and to this date the license review has not been completed. Consequently, the DOE failed in taking title to and disposing of the SNF in 1998. Therefore, the nuclear utilities sued for breach of contract damages and the federal government was ordered to compensate the utilities by paying for onsite storage of SNF.

The NWPA also granted the DOE authority to build a Monitored Retrievable Storage

(MRS) facility, which would be a centralized interim storage facility for SNF in which the stored SNF would be owned by the DOE. Local and state opposition killed any attempts to site a SNF storage facility. However, under the NWPA, an interim storage site cannot be built and the MRS facility can only be constructed after construction begins for the Yucca Mountain geologic repository.

A private consortium of eight nuclear utilities called Private Fuel Storage, LLC (PFS) submitted a license application to the NRC in 1997 to build and operate a private interim storage facility for the nation's SNF on the Goshute Indian Tribe's reservation in Utah. However, intense opposition by the State of Utah delayed the licensing and construction of this facility until PFS cancelled this project in December, 2012 15 years after it submitted the license application to the Nuclear Regulatory Commission. Since this facility was privately owned, the DOE would not have taken title to any SNF that might have been stored there.

President Obama established the Blue Ribbon Commission on America's Nuclear Future to explore other SNF management options besides the Yucca Mountain repository. On January, 2012, the Blue Ribbon Committee released its report which recommended "prompt" efforts to develop concurrently one or more consolidated storage facilities, one or more geological disposal facilities (concurrent so that interim storage does not become or is perceived by the public to become the de facto permanent solution) , and the transportation infrastructure . These recommendations would require Congress to change the Nuclear Waste Policy Act (1).

With no reprocessing, disposal, or off-site storage option available, the nuclear power plants' only option is to store their SNF onsite. Initially, the SNF was stored in pools filled with water (wet storage) to cool the used fuel until it could be shipped for reprocessing. The utilities then repacked the SNF in the storage pools into a denser configuration, increasing storage capacity five-fold. By 1986, the more-densely packed storage pools approached their storage capacity limit; therefore, the utilities had to build dry storage cask systems and moved the older SNF from the storage pools to dry storage casks (dry storage). The Nuclear Regulatory Commission (NRC) performed risk calculations on both wet and dry storage and found both had acceptable risks but dry storage is considered safer than wet storage (2) (3).

Texas has two nuclear power plant sites: Comanche Peak (two units) in Glen Rose and the South Texas Project (two units) in Bay City. These nuclear power plants are relatively young compared to others in the United States and are not expected to begin decommissioning for over three decades (projected decommissioning dates from 2047 to 2053). If the DOE is not able to take title of the SNF within the next four decades, then the SNF will remain onsite in dry storage even though the nuclear facilities will be decommissioned.

Currently the only option for SNF management is onsite storage, which was not envisioned in the initial plans of nuclear power. Even though it is considered safe, it is not an adequate solution. When a nuclear power plant is decommissioned (which can be after up to 60 years of operating life), the SNF remains onsite with nowhere to go, incurring an annual cost of $4.5 to $8 million (4) maintaining and guarding this waste (paid for by U.S. tax payers) and preventing the full site to be returned to unlimited use. The annual cost would decrease if the SNF were to be stored in one or two centralized locations instead of at each individual nuclear facility.

A solution for onsite indefinite storage of SNF is clearly needed and should not be further delayed. Since the federal government assumed responsibility for regulating SNF and for its final disposal, it should be the primary party seeking a permanent solution to managing SNF. Congress needs to either fund the license review of the Yucca Mountain geologic repository so that it could be constructed or amend the NWPA to allow for a new site selection process for one or two geologic repositories. Further, even if the Yucca Mountain facility is built, the volume of SNF has grown larger than the planned disposal volume of this repository. Therefore, either a second repository would be needed or the disposal capacity of Yucca Mountain would need to be enlarged, both actions require Congressional action to change the NWPA.

It is important to note that storage of SNF would still be required for decades even if definite plans to construct a geologic repository were implemented. If the Yucca Mountain repository is completed in 2020, the DOE estimated that interim storage would still be needed until 2056 (5). Moving the SNF from storage to disposal is calculated to require 24 years (6). If the Yucca Mountain repository is cancelled and a new site selection process begins, the earliest date for a geologic repository would be 2048 (1).

To assist with the continued need for storage options, one or more centralized storage facilities in which the DOE takes title to the SNF should be constructed so that SNF can be moved off of the nuclear power plant sites. The Blue Ribbon Committee recommended "prompt" efforts to develop one or more consolidated storage facilities concurrently with one or more geological disposal facilities. Public perception and concern about interim storage becoming the de facto permanent solution will be significantly reduced if the interim storage facility is built concurrent to efforts to site and build a geologic repository. Both DOE and the Electric Power Research Institute (EPRI) estimate that a centralized interim storage facility could be constructed within six years but may take longer if outside interferences during the NRC hearing process delay the licensing process (1) (7).

Any attempt by a private corporation to site a centralized interim storage facility would probably face the same opposition that stopped the effort by PFS. Finding a site that has local and state support would greatly enhance the chance of a private centralized interim storage site being successfully sited and constructed. The successful implementation of siting and constructing a geologic repository by the federal government would also alleviate opposition.

However, one main issue with a private centralized interim storage site is that the nuclear power plants would still have title to the SNF and would have to take back the waste if the storage facility closes without a repository available. The failure of the DOE to take title to the SNF in 1998 and the high probability that the DOE will not be able to take title to SNF in the next ten to twenty years makes the successful siting and construction of a private centralized interim storage facility highly uncertain and may be too uncertain for a private company to attempt. However, an interim storage facility owned by the federal government would allow the DOE to take title to the SNF stored in it. DOE often uses private entities to operate its national laboratories and other facilities so a DOE owned interim storage facility could conceivable be operated by the private sector.

Any federal or private program to manage SNF (disposal, storage, or reprocessing) needs to be established in a manner that reduces the uncertainty due to changing prevailing political opinions and minimizes local and state opposition through stakeholder meetings, finding volunteer communities, financial incentives, and a process that is considered fair and technically rigorous. Otherwise, the effort to license and build these facilities may result in nothing but wasted time and wasted money like the Yucca Mountain repository, the PFS storage facility, or the MRS facility. In looking at how to successfully site a facility, one should take into account current successfully sited and built radioactive waste disposal facilities such as the Waste Isolation Project Plant in New Mexico for transuranic waste and the Low Level Radioactive Waste Disposal Facility in Texas. If the methodology used for siting these two sites is built upon, the siting and construction of a SNF storage or disposal facility is not only feasible but could be highly successful.

Introduction

The first commercial nuclear power plant, the Shippingport Atomic Power Station in Pennsylvania, began producing electricity on December 18, 1957 (8). As of January 2013, 104 commercial nuclear power plants are in operation in the United States in 31 states and at 65 sites (some sites have more than one nuclear reactor). Currently, nuclear power generates about 20% of the electricity in the United States per year (9).

When electricity is produced by nuclear fission using uranium, high level waste (HLW) is also generated. High level waste is defined in Title 10 of the Code of Federal Regulations (10 CFR) §60.4 as "(1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted."

Irradiated reactor fuel is commonly known as spent nuclear fuel (SNF) and sometimes as used nuclear fuel to emphasize that about 99% of the fissionable content is still available in the fuel when removed from the nuclear reactor (10). This remaining 99% of the fissionable content can be retrieved and made into new fuel in a process called reprocessing, which produces HLW as defined in items (2) and (3) of 10 CFR §60.4. The DOE owns the HLW produced from reprocessing and is currently storing it at several federal sites; none of them are in Texas (11). Therefore, this report will concern itself only with the storage, reprocessing, and disposal of SNF from commercial nuclear power plants.

The assumption in the early days of nuclear power was that the SNF would be reprocessed so that long-term storage onsite would not be necessary. The federal government took responsibility for developing a site for disposal of the HLW. However, decades later, no disposal or reprocessing option is available and all of the SNF is stored at various nuclear reactor sites.

SNF is currently stored at 77 different sites:

- 63 sites have one or more operating commercial nuclear power reactors (two of which are in Texas),
- 4 sites are operated by the DOE (The DOE owns about 4% of the nation's SNF),
- 9 sites formerly had one or more operating nuclear reactors which have since been decommissioned, and
- One site in Morris, Illinois which was a failed reprocessing plant that never began operation.

The SNF at the sites without an operating commercial nuclear power reactor are referred to as stranded SNF (5).

Technical Descriptions

Nuclear Fuel and How Nuclear Energy is Generated

Fission occurs when a neutron hits the nucleus of an atom and splits the nucleus into two nuclei, releasing energy and one or more neutrons. The two nuclei form two new atoms called fission fragments or fission products, which are usually radioactive. A nuclear reactor is designed so that the neutrons released in the initial fissions produce more fissions and more neutrons which produce even more fissions so that a chain reaction forms in which fissions are continually occurring in a controlled manner (criticality). The energy released in the fissions is used to heat water which produces electricity in a turbine.

The fuel used in a nuclear reactor is uranium oxide. The two main naturally occurring isotopes (atoms which are the same element because they have the same number of protons but with different number of neutrons) of uranium are uranium-238 (99.2745% abundant) and uranium-235 (0.7200% abundant). Uranium-235 is fissionable and is the main source of fissions in a nuclear reactor. The uranium used in nuclear fuel in the United States is processed to have a higher concentration of uranium-235 than found naturally in the earth. Uranium-235 concentration for the light water reactors in the United States ranges from 3% to 5% (12).

The typical fuel rod for a nuclear reactor is a hollow cylindrical tube of a zirconium alloy (called the cladding) that is about half an inch wide and 12 to 15 feet long. Ceramic pellets of uranium dioxide, each pellet about the size of a thumbnail, are placed inside the hollow rod. A fuel assembly contains dozens to hundreds of fuel rods which are bound together and typically have a width of 5 to 9 inches. During operations a reactor core contains from 200 to 800 fuel assemblies, the total of which weighs about 100 metric tons.

Some of the fission products formed are strong neutron absorbers and are called poisons because they hinder criticality by absorbing neutrons which would have otherwise caused a new fission. Eventually the fission poisons build up to a level that it is no longer economical to use that fuel rod to produce electricity even though, for light water reactors, only 1% of the available fuel in that rod had been used. Subsequently, a fuel rod's useful life is typically 4 to 6 years. Usually a third of the fuel assemblies are removed from the core every 18 to 24 months (5) (13).

Neutrons may also be absorbed by the uranium nuclei and instead of causing fission will transform the uranium atom into an atom with a higher atomic number, such as neptunium, plutonium, americium, and curium. These atoms are called transuranic elements (TRU). Absorption of neutrons results in the production of fissile plutonium-239 and plutonium-241 in the SNF, which are used in most nuclear weapons.

What is Spent Nuclear Fuel

This removed nuclear fuel is SNF and contains radioactive fission products of various half-life values. A half-life is the amount of time in which half of the radioactive isotopes will decay. Many of the radioactive fission products have short half-life values and will decay completely away within five years. The radioactive decay releases energy which heats up the SNF. The SNF loses 80% of its heat in 5 years and 95% in 100 years (13). This heat emission of SNF is the main factor in determining how many fuel assemblies can be placed in a cask for storage, transport, or disposal.

Shielding is required to protect humans near SNF from a potential lethal radioactive dose. Even 10 years after being removed from the reactor core, the radiation field at one meter away from SNF would be over 20,000 rem per hour. A rem is a unit of radiation dose and a dose of 5,000 rem would incapacitate a person immediately and cause the person's death within one week (14). SNF is not hazardous to the environment if it remains intact but it would damage the environment if the spent fuel pellets are aerosolized and dispersed.

Reprocessing of SNF

Reprocessing the SNF chemically separates the uranium and plutonium from the other material in the used fuel rod. Reprocessing also produces liquid HLW, which, after solidification, weighs approximately 20% of the initial weight of the SNF (15). The HLW contains the fission products. The uranium and plutonium are returned to the reactor in the form of a new mixed oxide fuel rod.

The presence of fissile plutonium in SNF has raised proliferation concerns over reprocessing SNF. When contained within the nuclear fuel rod, plutonium is considered safe from being used in building a nuclear bomb (especially considering the high radiation field) but once separated from the other material it can more easily be used for building a nuclear bomb.

Reprocessing of SNF is technologically feasible. Russia, France, United Kingdom, India, and Japan reprocess SNF from nuclear power plants (16). France and the United Kingdom also reprocess fuel from other nations and the HLW produced is returned to the other nation. Reprocessing is done in the United States only by the federal government for military applications.

Proliferation of nuclear weapon grade material has not increased due to reprocessing of nuclear fuel for commercial energy production by these nations. Proliferation concerns should not prevent commercial reprocessing in the United States if proper security and policies are put in place to prevent unauthorized access.

The DOE possesses HLW from its programs and also the HLW generated by the commercial reprocessing operations at West Valley, New York. These wastes are managed by the DOE and are not regulated by the NRC. Any SNF disposal plans must include the disposal of the DOE HLW as well as commercial SNF (11).

Reprocessing does not eliminate waste but simplifies HLW management since the HLW generated contains less radioactivity and lower volume than the untreated SNF. The fission products have shorter half-life values than the TRU elements. After a hundred years, the activity from fission products would be mostly from strontium-90, yttrium-90, and cesium-137, which have half-life values of 29 years, 3 days (yttrium-90 is produced by decay of strontium-90), and 30 years respectively. Plutonium-239 has a half-life value of 24,000 years. However, if reprocessed, the plutonium-239 would be reintroduced into the reactor to undergo fission and split into two shorter-lived fission products. After 700 years, the activity of the TRU waste in an unreprocessed SNF rod will exceed the activity of the fission products. Additionally, the TRU radionuclides typically emit alpha radiation whereas fission products typically emit beta radiation. Alpha radiation inflicts more damage to a person (by at least one order of magnitude) than beta radiation if the radionuclide is inside the body by either ingestion or inhalation. Thus, it can be seen how reprocessing may simplify HLW management. (17)

The United States uses the once-through cycle in which the SNF rods leaving the reactor are disposed or stored as waste. The once-through cycle is also known as the "throw-away" cycle due to the fissile content contained in the SNF rods that is not being utilized to produce energy. The nuclear reactors used in the U.S. are light water reactors (either a boiling water reactor or a pressurized water reactor) in which 0.6 of a fissile atom is produced for every fissile atom consumed. For a 1,000 MW electric pressurized water reactor, the used fuel removed from the reactor and treated as waste in a typical refueling operation contains 400 pounds of fissile plutonium and 480 pounds of uranium-235, which is equivalent to one million tons of coal in energy content. Reprocessing of SNF for a light water reactor over 30 years would reduce the need for uranium ore by 40% (17).

Due to the buildup of non-fissile TRU waste in the used fuel, the SNF from a light water reactor can only be reprocessed a limited number of times (typically once). The construction of fast reactors would increase the efficiency of reprocessing even further. When neutrons are released in a fission event, they contain a portion of the kinetic energy released from the fission event and are called "fast". A light water reactor is designed to slow down the neutrons until they are "thermal neutrons" which are then used to cause fissions. In a fast reactor, fast neutrons are used for fissions and even the non-fissile TRU can be caused to undergo fission by a fast neutron. SNF from a fast reactor could feasibly be reprocessed an indefinite number of times, thus significantly increasing the efficiency of energy production (18). Research and development of commercial fast reactors has been started by the DOE but changes in the presidential administration have resulted in these projects being cancelled.

History of Spent Nuclear Fuel Management

The federal government has played a major role in the history of SNF management and therefore a review of the history of federal policy towards SNF storage, disposal, and reprocessing would help in understanding the current situation and analyzing the options for a path forward.

The assumption in the decades following the first commercial nuclear power plant in 1957 was that the nuclear power utilities would ship their SNF to be reprocessed and that a disposal site would be available for the HLW produced at the reprocessing facility. Therefore nuclear power plants were not designed and built for indefinite onsite storage of the SNF.

Because nuclear power plants were not built for indefinite storage, the federal government agreed to take on the responsibility of developing a HLW disposal facility.

Reprocessing

Political History

In 1956, the Chairman of the Atomic Energy Commission (AEC), a federal agency authorized to regulate and promote nuclear power which has since been replaced by the NRC and the DOE, announced a program to encourage the development of commercial reprocessing of spent nuclear fuel. By 1963, SNF was reprocessed in a project sponsored by the AEC at Idaho Falls on federal land (19).

President Ford issued a presidential directive in 1976 that discouraged commercial reprocessing and recycling of plutonium in the U.S. due to concerns over nuclear weapons proliferation. In 1977, President Carter issued a similar directive that deferred indefinitely all commercial reprocessing of plutonium, which ended commercial reprocessing of SNF since SNF contains plutonium. In 1981, President Reagan reversed this decision but commercial reprocessing did not resume since it is cheaper to use newly-mined uranium in a one-time use fuel cycle than to reprocess and reuse the uranium (19) (4).

Further, in 1993, President Bill Clinton discouraged commercial reprocessing in a policy statement and stopped the funding for specific DOE projects that were designed to develop new reprocessing technology. However, in 2001, President George W. Bush encouraged the development of commercial reprocessing in his national energy policy (19).

The DOE announced in February 2006 the creation of the Global Nuclear Energy Partnership (GNEP), a program in which the U.S. would "work with other nations possessing advanced nuclear technologies to develop new proliferation-resistant recycling technologies in order to produce more energy, reduce waste and minimize proliferation concerns (20)." One of GNEP goals is the development of new reprocessing technologies and advanced nuclear reactors which are designed to optimize reprocessing (21). However, on June 29, 2009, President Obama canceled the GNEP Programmatic Environmental Impact Statement for the Technology Demonstration Program (first step in starting this program) because the DOE "is no longer pursuing domestic commercial reprocessing, which was the primary focus of the prior Administration's domestic GNEP program (22)."

History of Commercial Reprocessing Plants

In 1964, a permit was issued to a commercial reprocessing facility in West Valley, New York by the AEC. This facility reprocessed fuel generated both by commercial nuclear power plants and by the defense program for the federal government. Stricter regulations were issued which forced this facility to shut down in 1972 for upgrades but the operator decided to close the facility permanently because the upgrades were not considered economically feasible (19).

In 1967, General Electric Company was issued a license for a reprocessing facility at Morris, Illinois. The process worked well at the pilot scale but failed during pre-operational trials of the production plant. General Electric closed the facility without processing any SNF in 1972. Currently, SNF shipped to this facility is still being stored in a fuel storage pool (19) (16).

Beginning in 1970, Allied-General Nuclear Services Company started construction of a reprocessing plant at Barnwell, South Carolina but stopped in 1977 due to President Carter's presidential order (19) (16).

In 1992, with no domestic reprocessing facility, Long Island Power Authority sought to have its SNF processed in France by the firm Cogema, but President George H.W. Bush prohibited this shipment (19).

Currently, no economic driver exists for commercial reprocessing in the U.S. since the one-time use fuel cycle is cheaper than the projected costs of reprocessing. Studies by the National Academy of Sciences in 1996 and the National Research Council in 2007 stated that reprocessing SNF was not cost effective. The National Research Council report also concluded that development of a commercial program would not be possible without significant funding by the DOE (19). However, federal government funding for commercial reprocessing projects has been plagued by political uncertainty. Presidential orders have alternated between encouraging commercial reprocessing and prohibiting commercial reprocessing. If the federal government were to change course and allow commercial reprocessing again, it is estimated that the first commercial reprocessing facility would not be built and available until at least 2030 and maybe as late as 2040.

Further, the option of having another country reprocess SNF generated in the U.S. was effectively closed by Presidents Bush's decision to stop Long Island Power Authority from reprocessing its SNF in France in 1992. Even if Long Island Power Authority did reprocess its SNF in France, it would still need to take back the HLW generated from the reprocessing activity and store it onsite until a HLW repository opened.

Even though the reprocessing option is not available in the U.S. due to higher costs and the uncertainty of federal government funding, the reprocessing option should still be considered as a possible future choice. Advances in reprocessing technology or other changes, such as policy or economic, may make reprocessing more advantageous than the once-through or the "throw away" cycle. The unused fissile material in the SNF represents a considerable amount of energy that could change the view of SNF from a waste to an energy resource. Additionally, specific isotopes that are useful in research, industrial processes, and medicine are contained in the SNF and could be isolated from the other fission products in a reprocessing facility. Disposing of SNF in a non-retrievable manner may be viewed as a mistake by future generations. Storing or disposing of the SNF in an easily retrievable but safe and environmental sound manner should be considered as one option in managing this waste.

Nuclear Waste Policy Act of 1982 and its amendment in 1987

After President Carter banned commercial reprocessing for plutonium in 1977, he convened an "Interagency Review Group on Nuclear Waste Management" to develop a national policy for nuclear waste management. The recommendations in the report issued two years later by this group resulted in the National Waste Policy Act (NWPA) of 1982 (23). The NWPA and its amendment in 1987 is the legal framework in which the federal government is able and authorized to manage SNF and HLW in the United States to the current day.

Under NWPA the federal government has the sole regulatory authority over SNF. Any repository developed is to be characterized by the DOE and the repository licensed by the Nuclear Regulatory Commission (NRC). Specifically, the NRC is responsible for codifying the requirements and criteria for approving construction, operation, and closure of the repository including safeguards, security, and protection of workers from radiological exposures. The Environmental Protection Agency (EPA) determined the standards used by the NRC for protecting the general environment from offsite releases during the operational and post-closure periods. Worker protection, except for radiological exposure, was the responsibility of the Occupational Safety and Health Administration and the Department of Transportation (DOT) and NRC regulate different aspects of HLW transportation (4).

Act of 1982

Congress wrote the NWPA knowing that a Congressional mandate would be necessary to overcome opposition to the site selected for the geologic repository (the disposal method chosen in the NWPA) for HLW. The state chosen as the repository site could veto the decision but this veto could be overridden by a Congressional vote in both houses. Additionally, the Act stipulated that two repositories were to be built to alleviate the feeling by the chosen state that it was being unfairly assigned the task of taking all of the country's waste. The assumption, which was not stated in the NWPA, was that one repository would be in the West and the other in the East (4).

The NWPA established the Nuclear Waste Fund (NWF) to fund SNF disposal and was to be funded by a fee of $1 per megawatt hour of nuclear power generated. In exchange for funding the NWF, the DOE is to take title to, transport, and dispose of the SNF and HLW by January 31, 1998. The NWPA authorized the DOE to enter into Standard Contracts (see 10 CFR Part 961) with any person who has generated or holds title to SNF or HLW (mostly commercial nuclear power plants) which stipulated the requirements for funding the NWF and the DOE's taking of the SNF (24).

The NWPA provided two options for DOE to store SNF. The first option was for temporary storage, called federal interim storage, for a specific volume of SNF under specific conditions. The authority to provide federal interim storage expired in 1990 and was never used. The second option was to operate a Monitored Retrievable Storage (MRS) facility (24).

<u>Amendment of 1987</u>

Congress amended the NWPA in 1987 due to

- The intense opposition to the DOE site selection process for both the MRS facility and the geologic repository and
- The lengthy and expensive (about a billion dollars per site) characterizing process (23).

The amendment selected the Yucca Mountain site in Nevada as the only site to be characterized for the geologic repository and offered a financial incentive of $20 million per year to Nevada. The disposal capacity of the repository was limited to 70,000 MTHM (metric ton of heavy metal) (23).

Congress constricted the construction and operation of the MRS facility to alleviate concern from the host state that the MRS facility would become a de facto permanent solution. The NRC could only issue a construction license for the MRS facility after the NRC has issued a license for the construction of the geological repository at Yucca Mountain. The amendment also limited the size of the MRS to 10,000 MTHM of SNF before the geologic repository accepted its initial shipment of HLW and 15,000 MTHW afterwards. Consequently, the MRS facility could not accept waste for storage until, at the earliest, three years before the repository opens. (24) (23).

Further, the amendment offered a financial incentive of $10 million per year to the state chosen to host the MRS site. The DOE had chosen Oak Ridge, Tennessee before the amendment for the site of the MRS facility but due to political opposition the amended NWPA prohibited Oak Ridge to be the site. Additionally, the DOE was not allowed to site the MRS facility in Nevada since it was the host state to the geologic repository. The Office of the United States Nuclear Waste Negotiator was established and authorized to find sites for and to negotiate agreements with states or Native American tribes to host the MRS facility. The position was to be appointed by the President. Any agreement would need to be approved by Congress before going into effect (4) (23).

Efforts to Site and Build a Geologic Repository

In 1983, the DOE chose several locations for further consideration as sites for a geologic repository:

- Hanford in Washington State,
- Yucca Mountain in Nevada,
- Davis Canyon in Utah,
- Lavender Canyon in Utah,
- Deaf Smith County in Texas,
- Swisher in Texas,
- Vacherie dome in Louisiana,
- Richton Dome in Mississippi, and
- Cypress Creek Dome in Mississippi.

The sites were reduced to Hanford, Yucca Mountain, Davis Canyon, Deaf Smith County, and Richton Dome in 1986 and to Yucca Mountain (geologic formation of tuff), Deaf Smith County (salt deposit), and Hanford (basalt) in 1987 (15) (25).

Due to opposition from elected officials at each site under consideration, rising costs, and a decrease in the projected waste volumes, the DOE announced in May 1986 that only one site would be picked for a geologic repository and stopped all efforts at siting the second site (23).

In 2002, the DOE issued a formal finding that the Yucca Mountain site was suitable for a geological repository and President Bush recommended this site to Congress. The State of Nevada filed an official "Notice of Disapproval" which both houses of Congress voted to override (13). The NWPA stipulated that the DOE then had 90 days to apply to the NRC for a construction license but the application was not submitted until June 2008 due to litigation and insufficient funding. According to the NWPA, the NRC had up to four years to complete the license review.

In 2009, President Obama said that the Yucca Mountain site was "no longer considered a workable option" and in 2010, the DOE requested to withdraw the application. The NRC stopped reviewing the application in 2011 since no funds were allocated by Congress for this review and no additional funds have been allocated to the present day (11) (4). A total of $11 million for reviewing the application that was allocated before fiscal year 2011 was not spent (26).

Several parties petitioned the federal court to force the NRC to resume reviewing the Yucca Mountain repository license application. The United States Court of Appeals for the District of Columbia Circuit ordered the NRC on August 13, 2013 to use the unused $11 million dollars to work on the Yucca Mountain application. Judge Brett M. Kavanaugh wrote that "the president may not decline to follow a statutory mandate or prohibition simply because of policy objections (26)." The NRC decided in November 18, 2013 that the $11 million would be used to complete the Safety Evaluation Report, which is the first step in the license application review, and requested the DOE to prepare a supplemental environmental impact statement needed to complete the environmental review (27). Additional work cannot be completed after the $11 million is spent unless Congress allocates additional funding for reviewing the license application.

The DOE had spent almost $15 billion on characterizing the Yucca Mountain site and completing the construction license application, of which about $9.5 billion was paid by the Nuclear Waste Fund (1) (28).

Impacts of the Failure to Open a Repository

Due to the failure to construct a disposal repository, the DOE was unable to take title and dispose of the SNF from the commercial nuclear power plants and thus breached the Standard Contract. The majority (74 out of 76 standard contracts) of the persons with SNF have filed lawsuits to recover damages from this breach of contract (5). The federal courts have found the DOE in these cases to be in partial breach and the federal government is required to compensate the utilities for damages (24) by paying for the onsite storage until the DOE is able to remove the SNF from the reactor sites according to the "waste acceptance" schedule in the contract (23). Damages include the capital costs for additional wet storage racks, construction of the dry storage facilities, purchasing and loading the dry storage casks and canisters, and the personnel cost to design, license, and maintain these storage facilities (5).

The federal government may not use the Nuclear Waste Fund to pay the utility since the NWPA restricts this fund to only pay for disposal. Therefore, the damages are to be paid from the U.S. Treasury Judgment Fund, which is managed by the U.S. Department of Justice and is a permanent, indefinite appropriation used by the federal government to pay damages in cases against the United States. The first payments were made in 2000. As of November 2012, a total of $2.6 billion has been paid. The total payments by 2020 are expected to range from $11 billion to $21 billion and to cost $500 million per year after 2020 (1) (5) (23).

The U.S. Court of Appeals for the District of Columbia Circuit ruled on November 19, 2013 that the nuclear power plant operators do not have to pay into the Nuclear Waste Fund anymore. Annually about $750 million in fees was collected for the fund which was expected to be at $28 billion at the end of 2012, earning $1.3 billion in interest each year (29).

In addition to suits against the federal government several states (California, Connecticut, Illinois, Kentucky Maine, Oregon, West Virginia, and Wisconsin) have passed laws that prevent or hinder the construction of a new nuclear power plant in their state unless a disposal or reprocessing option is available for the SNF (30).

Efforts by Federal Government to site a storage site

In 1987, the DOE proposed to build the MRS facility on federal land near Oak Ridge, Tennessee because the DOE already operated nuclear energy research facilities in that town. Therefore, the technical infrastructure and skilled personnel needed for the MRS facility was already locally available. However, opposition from state and federal officials resulted in the prohibition of Oak Ridge being the site of the MRS facility in the 1987 amendment of the NWPA (23).

The Office of the Nuclear Waste Negotiator sent out formal invitations to states, local governments, and Indian tribes in June 1991. In 1992, seven communities (including 5 Indian tribes) expressed interest in hosting the MRS facility and each received $100,000 in DOE grants. The communities selected for a second phase of study would have be eligible for several million dollars in grants but no second phase grants were awarded. The host states for all of the seven communities opposed the siting of the MRS facility in their state (4). In 1993, Congress blocked funding for future grants due to the opposition which effectively stopped any further progress on siting the MRS facility. In January 1995, the authority of the waste negotiator expired and was not extended by Congress (23).

Private Efforts to construct an interim storage site

After the federal government failed in selecting a site for the MRS, eight nuclear utilities (Xcel Energy, Genoa Fuel Tech, Florida Power and Light Company, Southern Nuclear Operating Company, Entergy, Indiana-Michigan Power Company {American Electric Power}, GPU Nuclear Corporation, and Southern California Edison Company) formed a private consortium called Private Fuel Storage, L.L.C. (PFS) (31).

In 1996, PFS signed an agreement with the leadership of the Skull Valley Band of the Goshute Indian Tribe, who had also volunteered for the MRS facility, to construct and operate a dry cask storage site on their reservation in Utah. A lease for 25 years with a renewal option for 25 more years was signed between PFS and the Goshute Indian Tribe but required approval by the Bureau of Indian Affairs (31).

The majority of the residents of Utah and Utah's congressional delegation opposed the PFS interim storage facility. However, the State of Utah had limited power to interfere due to the sovereign rights of Indian tribes which prevents the jurisdiction of state and local governments from entering American Indian reservations (4).

PFS submitted a license application to the NRC to build an Independent Spent Fuel Storage Installation (ISFSI) for 40,000 MTHM in 1997. The SNF would be stored vertically in steel and concrete storage cask on a concrete pad. The volume of 40,000 MTHM is sufficient to store the SNF from the eight utilities that formed PFS and also SNF from other nuclear power plants. The goal of the facility was for a "safe, efficient, and economical alternative to continued SNF storage at reactor sites (31 p. xxxii)." The application also included a proposal to construct and operate a 32 mile long rail line on public land administered by the Bureau of Land Management of the U.S. Department of Interior, who had to approve the rail construction (31).

NRC's review of the application was delayed by legal battles and the license was issued on February 21, 2006. The license authorized the facility to store SNF for 20 years with a renewal option for another 20 years (4). After 40 years of storage, it was expected that a repository would be available for the stored SNF to be disposed. If a repository was not available at the end of 40 years, then the waste generators would still be responsible for their SNF and would be required to transfer the SNF from the storage facility back to the site of the nuclear power plant (31).

PFS never initiated construction of the ISFSI due to two actions of the Department of the Interior:

- The Bureau of Indian Affairs disapproved the lease of the tribe's land due to "uncertainty concerning when the SNF might leave trust land, combined with the Secretary's practical inability to remove or compel its removal once deposited on the reservation" (32) and
- The Bureau of Land Management denied the right of way over federal land for the railway. Without the use of the railway, SNF would have to be transported by truck, increasing the difficulty, risk, cost, and time for transportation (4).

The Goshute tribe and PFS filed a federal lawsuit in July 2007 to overturn these decisions claiming that the State of Utah applied political pressure to the U.S. Department of the Interior (DOI) (23). The federal court found the DOI's decisions to be arbitrary and capricious and remanded it for reconsideration (4) (33). However, the DOI did not change its decisions and in a December 20, 2012 letter to the NRC, PFS requested that its license be terminated (34)]. The planned interim storage facility was canceled after 15 years of planning and over $70 million of legal and licensing fees (23).

Blue Ribbon Commission and its Recommendations

In 2010, the Obama administration directed the DOE to establish the Blue Ribbon Commission (BRC) on America's Nuclear Future. The BRC is an advisory body of experts to the DOE who were to review the nuclear waste management alternatives to disposal at the Yucca Mountain site. The BRC issued a report on their findings in January 2012 (11) (13).

The BRC recommended "prompt" efforts to develop concurrently one or more consolidated storage facilities, one or more geological disposal facilities, and the transportation infrastructure required to transport SNF from the reactor sites to the storage and disposal sites. The BRC recommended that the storage and disposal facilities be developed concurrently so that interim storage does not become or is not perceived to potentially become the permanent solution by the public (4). Any of these recommendations would require legislative changes to the Nuclear Waste Policy Act (1).

A DOE report in January 2013 listed the following proposed earliest dates of when the facilities could be operational: a pilot interim storage facility by 2021, a larger interim storage facility by 2025, and a geologic repository by 2048 (1). The proposed dates include time for site selection, licensing, and construction. The DOE stated that legislative changes to the NWPA and funding reform, such as allowing the Nuclear Waste Fund to pay for interim storage, would be needed (24). DOE estimated that if the Yucca Mountain geologic repository was completed in 2020, interim storage would still be needed until 2056 because of the large amount of SNF (5).

Further, according to the Government Accountability Office, several decades will be needed to transport all of the SNF to a geologic repository. By 2040, most of the reactors currently in operations will be closed (13).

Waste Confidence Rule

The Waste Confidence rule is a generic action in which the NRC found reasonable assurance that SNF could be stored safely and with a minimal impact on the environment until a disposal option becomes available. The rule arose from an NRC statement that it "would not continue to license reactors if it did not have reasonable confidence that the wastes can and will in due course be disposed of safely." The Waste Confidence rule is used for the review of new reactor licenses, license renewals, and Independent Spent Fuel Storage Installation (ISFSI) licenses to prevent the need for litigation over waste management and disposal issues for each license application (35) (36).

In 1984 the Waste Confidence rule found "reasonable assurance that one or more mined geologic repositories for commercial HLW and SNF will be available by the years 2007-2009" and stated that SNF storage is acceptable for at least 30 years beyond the expiration of the reactor's operation license. The complete duration of SNF storage includes the operational period (40 years of the original license and an additional 20 years renewal) of the nuclear reactor and includes both wet and dry storage, which results in a total of 90 years of storage for the oldest fuel. The NRC also found "reasonable assurance that safe independent onsite or offsite spent fuel storage will be made available if such storage capacity is needed." The rule was revised in 1990 to change the date for the repository to the "first quarter of the twenty-first century" (35).

The most recent Waste Confidence rulemaking in 2010 modified the prior rule by changing the date that disposal capacity will be available from the "first quarter of the twenty-first century" to "when necessary" and lengthening the time that SNF can be stored safely to 60 years beyond the expiration of the reactor's operation license (a total of 120 years for the oldest fuel). The NRC analyzed degradation mechanisms and used the fact that the temperature of the spent fuel decreases over time which decreased degradation to determine these safe storage time periods (35) (37).

New York, Vermont, Connecticut, New Jersey, the Prairie Island Indian Community in Minnesota, and several environmental groups petitioned for review of the 2010 update to the NRC's waste confidence rule. On June 8, 2012, the U.S. Court of Appeals for the District of Columbia Circuit ruled that the Waste Confidence rule is a major federal action, and therefore requires an environmental impact statement or a finding of no significant environmental impact. Additionally, the court found that the NRC was deficient in concluding that disposal will be available "when necessary" which prevented the NRC from determining the effect if disposal does not become available.

In response to the Court's decision, the NRC decided to stop all licensing activities (mostly reactor license renewals) that rely on the Waste Confidence rule until they complete the Waste Confidence Generic Environmental Impact Statement (GEIS) and revise 10 CFR Part 51 accordingly which will be no later than September 2014. The NRC released the draft GEIS and the proposed rule change in September, 2013 (retains the determination that SNF can be stored safely 60 years after reactor shutdown).

The draft GEIS includes both low and high burnup fuel and analyzed three timeframes: short-term (60 years storage after reactor shutdown), long-term (160 years storage after reactor shutdown), and indefinite in which a repository never becomes available. The long-term and indefinite timeframe analysis assumed that the SNF storage canister and cask would be replaced, requiring the construction of a dry transfer system facility, every 100 years (38).

Additionally, NRC is currently conducting an extended storage effort (expected to be completed by 2020) for storage over 120 years which includes:

- Developing technical information concerning safety issues and environmental impact,
- Developing an environmental impact statement for a waste confidence decision for storage up to 300 years after reactor shutdown, and
- Revising the Waste Confidence rule appropriately.

The NRC states that any revisions to the waste confidence rulemaking does not indicate approval for waste storage for this time period and that any authorization for waste storage time is given through the licensing of the ISFSI and certification of the storage cask (38) (39).

Recent Developments in Response to the BRC's Recommendations

The Nuclear Waste Administration Act of 2013 (senate bill 1240) was introduced by Senator Ron Wyden (democrat from Oregon) based on the recommendations in the report released by the BRC. The bill, if made into law, would establish a new independent agency in the executive branch to manage HLW and would authorize the siting, construction, and operation of repositories and storage facilities, including a pilot program for the storage of priority waste. The bill would require the federal government to enter into a consent agreement with the host state and each affected unit of general local government or Indian tribe. The bill was referred to the Senate Energy and Natural Resources committee on June 27, 2013 and had a public hearing on July 30, 2013 (40). Disagreement between the House of Representatives and the Senate over the fate of the Yucca Mountain Disposal Facility has stalled further progress on this bill.

Representatives of state governments are communicating with the federal government their concerns about the potential future siting process and operation of any HLW disposal or storage facility. The Environmental Council of the States issued recommendations that the "states be considered partners with all appropriate federal agencies and should have a clear decision-making voice on activities proposed within their borders" (41). Past experience has shown that siting a radioactive waste facility often fails when the state strongly opposes it even though in nearly every case the affected local governments strongly supported the facility because of the jobs created and as a means of economic growth for the local area (42). Both local and state support will be needed to successfully site a HLW disposal or storage facility.

Some support for hosting a nuclear facility have been expressed by local communities or Indian tribes, such as those volunteers for a GNEP project in 2006. It is not possible to gauge the number of communities or the level of support for hosting a HLW repository or storage facility since new legislation for the siting process has not yet been passed and no call for volunteers has been issued. A search of news stories or Internet sites indicated interest from the state of Arizona to store SNF and one community actively promoting itself to be a site of an interim SNF storage facility: the Eddy Lee Energy Alliance (ELEA).

The ELEA is a limited liability corporation consisting of Eddy and Lea County in New Mexico and the cities of Carlsbad and Hobbs, which are located in a region called the New Mexico's Nuclear Corridor. The ELEA was formed in 2007 to obtain a grant under the GNEP as a possible site for a reprocessing plant and was one of eleven sites chosen as a potential candidate. Strong public support for the project was shown in three public meetings which were attended by several hundred local residents (43) (44). ELEA sent a notice of intent, dated February 26, 2013, to the NRC to submit a site-specific license application in 2015 for a consolidated SNF storage facility in response to the DOE's January 2013 Strategy Document for implementing the BRC's recommendations (45). ELEA has chosen the French firm AREVA to build the above-ground interim storage facility on 1,000 acres between Carlsbad and Hobbs which is estimated to create 150 jobs (armed guards, nuclear scientists, engineers, managerial and administrative staff) (46). No further developments have been made public since this report was written.

The Arizona Legislature passed a non-binding resolution on April 24, 2012 that requested the federal government to consider Arizona as the site of a SNF storage facility (47). The Arizona Energy-Education Fund Coalition is an assembly of stakeholders from the private sector, government, education and energy industries that has formed to support the siting of an interim or permanent storage facility for HLW in Arizona (48) (49).

Current Practices for storing SNF

Wet Storage

When nuclear fuel is removed from the reactor, it is placed inside a pool of water (called wet storage). The water provides both cooling for the hot SNF and shielding from the radiation for the workers at the reactor. The water in the pool is circulated to maintain the temperature at 120 °F; otherwise the water would boil. Without cooling, the SNF temperature can increase by hundreds or thousands of degrees Fahrenheit (13).

A storage pool has a stainless steel liner and reinforced concrete walls that are several feet thick. The fuel rods are stored vertically in the pool that is typically 40 feet deep so that over 20 feet of water is over the fuel rods. The water is filtered and the chemistry is carefully controlled to minimize corrosion. Consequently, a storage pool needs continual maintenance and a constant supply of electricity (5) (13).

The pool for a pressurized water reactor is at or below ground level, but for a boiling water reactor, the pool is about three stories above ground level, near the reactor vessel (13).

Utilities only allow SNF to occupy up to approximately three-fourths of the storage capacity in order to reserve space for at least one full reactor core load of fuel. The storage capacity of the pools range from 2,000 to 5,000 fuel assemblies (average of about 3,000) throughout the U.S. (5). The number of fuel assemblies that can be placed in a storage pool is limited by the decay heat emitted by the SNF and criticality concerns.

The storage pool and all pool activities are licensed by the NRC under the reactor's 10 CFR Part 50 operational license.

Denser Arrangement

Fuel storage pools were initially designed to store the SNF for a limited time until they cooled to a sufficiently low temperature at which time they could be shipped for reprocessing. Consequently, the pools were designed to only hold about one and one-third of a core's full loading of fuel rods. However, when no reprocessing or disposal option became available, utilities built new fuel storage racks to pack the fuel rods in a more dense formation, increasing the storage capacity five-times (13) (23) (50).

The NRC conducted safety studies and approved the more densely packed configuration provided that cooling is adequate, structure integrity is maintained, and steps are taken to prevent criticality (13). Neutron absorbers were added to the pool to negate any criticality concerns. The isotope Boron-10 is a strong neutron absorber and placed in the pool in the form of boron carbide in an aluminum metal matrix (51).

Even with this denser configuration by 1986, fuel storage pools were nearing their storage capacity limit (13) (23). When the pool approached its storage capacity, utilities began to move the older SNF into "dry cask" storage (28).

Risks of Accidents

The highest risk of wet storage is a loss of coolant (water) resulting in a self-sustaining fire. Risk is defined as the probability of an accident occurring multiplied by the consequences of the accident. A self-sustaining fire is a low probability, high consequence event (13).

A self-sustaining fire can only occur if enough water is lost so that the top half of the fuel rods are uncovered and the fuel reaches a temperature of 1,830 °F. The initiating event for the loss of water would need to be an earthquake over the design limit, terrorist attack, or other similar event that also disables the means to add more water to the pool. At 1,830 °F, the zirconium alloy can react with oxygen and release energy, burning like a welding torch. This fire can spread to other spent fuel rods if they are densely packed.

The SNF storage pool is designed and constructed to prevent and mitigate a self-sustaining fire (13).

An additional concern is that if the water heats up and produces steam, the steam can react with the hot zirconium cladding and produce hydrogen gas that can cause an explosion if it is mixed with oxygen (13).

The NRC calculated the risk of an individual early fatality (death within months verses a cancer death decades later) within one mile from a self-sustaining fire to be 1×10^{-7} per year (one death per ten million years) one month after the reactor has been shut down and it decreases to 2×10^{-8} per year (one death per fifty million years) five years after reactor shutdown. The risk of an individual latent cancer fatality within ten miles from a self-sustaining fire is 7×10^{-9} per year (one death per 143 million years) for both one month and five years after reactor shutdown. These risks were the maximum calculated risk assuming the highest possible radioactive content of the SNF and the highest seismic risk. The maximum calculated risks are an order of magnitude lower than the NRC safety goal and is thus regulatory acceptable (2).

On March 11, 2011, an earthquake and a tsunami hit the Fukushima Prefecture of Japan, causing a loss-of-coolant accident in Units 1 to 4 of the Fukushima Dai-ichi reactors. The reactors lost all power: power generated by the reactors, offsite power supplied by other power generators, and emergency onsite diesel generators. Therefore, they were unable to continue to pump water. As a result of the loss of coolant and of hydrogen gas explosions, some of the nuclear fuel rods in the reactor melted and released radioactive material (52).

The dry storage cask onsite and storage pools outside of the reactor buildings were not damaged during this incident. The spent fuel storage pool inside the reactor containment structure was damaged due to rubble falling onto the pool when hydrogen explosions damaged the building. Additional damage may have occurred due to the loss of electricity which resulted in no ability to monitor the pool or add additional water. The SNF stored inside the damaged pool appears to be undamaged and efforts to remove them from the damaged pool began in November, 2013 and are expected to be completed at the end of 2014. Coolant water is currently being added to the storage pools as needed (5) (53).

Additionally, the NRC has determined that some storage pools have contributed to tritium and other radionuclide contamination of groundwater (along with other parts of the nuclear reactor). These leaks were determined to be within regulatory limits and therefore no significant public exposure or health impact resulted from these leaks (5) (54).

Dry Cask Storage of SNF

Dry cask storage is synonymous with Independent Spent Fuel Storage Installation (ISFSI) because all but one ISFSI site (the failed reprocessing plant at Morris, Illinois) uses dry casks (5). The first commercial onsite dry storage facility was built at the Surry Nuclear Power Plant in Virginia in 1986 (55). By 2020, it is expected that all reactors will be using dry storage casks onsite (23).

Dry cask storage is only feasible after the heat emitted by the spent fuel rod has decreased to a level sufficient for natural convection of ambient air to maintain the fuel temperature below 752 °F. The Zircaloy cladding may be damaged at temperatures above 752 °F.

Typically, five years of cooling after the fuel rod has been removed from the reactor core is considered necessary before it can be transferred to dry storage (13) (23). However, the NRC has authorized transfers into dry cask storage for SNF removed as early as 3 years from the core (28) and states that fuel may be moved to dry storage after only one year (55). The actual time for moving SNF into dry cask storage is on average ten years (28).

Description of Dry Storage Cask System

The SNF is placed inside a thin-walled steel canister which is filled with the inert gas helium to prevent oxidation from damaging the structural integrity of the canister. The lid is either welded or bolted shut. The canister is then placed inside a larger stainless steel or thick-walled concrete dry storage cask (which has an inner steel liner). The casks are cylindrical and the concrete thickness provides shielding from the radiation. Vents are placed on the top and bottom of the dry storage cask for convective heat transfer.

The casks are stored either vertical on a concrete pad or horizontal in a concrete vault in which the thick concrete wall of the vault provides radiation shielding. Some more recent systems have the dry storage cask placed in a hole which increases the security from attack or weather and reduces the radiation exposure. The dry storage cask containing hotter SNF may protrude from the hole by two feet to increase the cooling from air flow. The pad or vault is secured with safety systems and a security infrastructure, including radiation detection devices and intrusion detection systems (1) (5) (13) (23) (55).

The NRC has licensed over 50 different dry storage casks manufactured by about a dozen companies. The NUHOMS 61BT storage canister weighs 22 tons empty and 44 tons when loaded with SNF. A dry storage cask, fully loaded, can weigh from 100 to 180 tons (5) (13) (23) (55).

The number of SNF assemblies that can be stored in a dry storage cask is limited by the decay heat emitted by the used fuel. The longer the SNF is stored in the cooling pool, the lower the decay heat, and the more fuel assemblies that can be placed in the dry storage cask. If the cooling time in the pool is from 5 to 15 years, a less expensive storage cask can be used that does not need to be built to withstand a higher heat load (23).

By the end of 2012, about 200 dry storage casks out of 1700 in the United States (U.S.) contained high burnup fuel and nearly all of the SNF being loaded into dry storage casks is high burnup (56) (57).

Transfer from wet storage to dry storage

The first step to transferring a fuel assembly from wet storage to dry storage is to place the dry storage steel canister inside a transfer cask (usually has a four inch wall thickness of steel and lead) and then lower both into the storage pool. The water in the pool offers excellent radiation shielding for the transfer. A crane is used to place the spent fuel assembly into the dry storage steel canister. Afterwards, the transfer cask and its contents are lifted up from the pool and any water remaining inside it is removed using either vacuum drying or a force helium system. After drying, the lid is welded or bolted onto the canister. The spent fuel in the transfer cask is moved to the dry storage facility and the dry storage canister is transferred from the transport cask to the dry storage cask. Typically, before the transfer, the transfer cask is placed on top of the dry storage cask and the two casks are coupled together with a mating device (7) (13).

Transferring a cask from wet to dry storage requires several weeks. Some of the more time consuming steps in this process include:

- Mobilizing equipment requires two weeks and demobilization requires an additional two weeks,
- Training personnel, which includes practicing the procedure, and
- Actual transfer (typically a week), which includes drying and sealing the canister, transportation to the storage pad, and placement into the dry storage system.

In addition, constraints that limit the number of canisters that can be loaded concurrently are heavy lifting capacity, available space in the SNF storage pool, and available space to dry and seal the transportation canister (13).

Licensing and Certification

The NRC issues a certificate of compliance for a dry storage cask (which includes the canister to be placed inside) only if the manufacturer can demonstrate that the cask will protect the SNF in case of extreme events such as flood, earthquakes, tornado missiles, temperature extremes, and terrorist attack. Computer analyses, comparisons with other designs, component testing, and scale-model testing are all utilized in testing the cask and reviewing its design. Physical tests performed on the cask include being dropped from the maximum height possible during transfer operations, being tipped over, fires, and floods. The manufacturer must also commit to follow an approved quality control program that ensures the containers continuously meet design specifications. The certificate of compliance is issued for storage not to exceed 20 years, which may be renewed for up to an additional 40 years (13) (55) (58). Different criteria and tests are required for transportation certification.

The dry storage facility is licensed independently from the nuclear reactor as an ISFSI and is considered to be independent from the reactor even though they are located at the same site. The ISFSI license is either a site-specific license or a general license. Of the ISFSIs licensed by March, 2013, 48 are operating under a general license and 15 under specific licenses (23) (58).

If the planned ISFSI is to be constructed on the site of a facility already licensed to store SNF (such as a nuclear reactor) and a NRC certified cask is to be used, then the ISFSI can be authorized by a general license. A general license saves time and money by avoiding duplicating effort already performed during the license application process for the nuclear reactor, such as the environmental impact statement and seismic reviews. The Licensee must review and modify their existing procedures — such as safety, emergency preparedness and response, and security — to accommodate the ISFSI. Three and a half years is the typical time from designing the ISFSI to the first loading of SNF, assuming a NRC certified cask is used otherwise an additional two to three years will be needed (7).

If a person is not authorized to apply for a general license, he must then apply for a site specific license. Six years is the typical time from designing the ISFSI to the first loading of SNF, assuming a NRC certified cask is used (7).

An ISFSI may be licensed for 40 years with the option for a renewal of another 40 years (10 CFR §72.42). The GEIS from the waste confidence rule will also apply towards renewing the ISFSI license (38).

Some utilities have had public opposition to plans to store SNF onsite in a dry cask storage system but no dry cask storage has been prevented (59). However, some limitations have been placed on some utilities by the host state (60). For example, Minnesota law (M.S.A. §216B.243) requires the facility to "address the impacts of continued operations over the period for which approval is sought" before the state will issue a certificate of need for additional storage of SNF (30).

Stranded SNF at decommissioned reactors

When a reactor is decommissioned, all of the SNF in wet storage is transferred to dry cask storage and the storage pool is decommissioned. However, the entire nuclear power plant site cannot be decommissioned and returned to other use because the SNF is in dry storage. A common term used for the SNF in this situation is stranded SNF. In the U.S., nine former operating nuclear reactor sites have been decommissioned with SNF remaining onsite: seven have the SNF in dry storage and the other two are in the process of transferring the SNF from wet storage to dry storage (5) (13). The number of sites with stranded SNF will increase as reactors close without an off-site storage or disposal option available.

If any of the stranded SNF at these sites requires repackaging, there is no SNF storage pool to use to perform the transfer, which would increase cost, risk, and exposure to workers for any transfer. Either the SNF would need to be transported to a storage pool at another reactor site or a new transfer facility must be constructed.

One option that has been considered is to move the SNF from the decommissioned nuclear reactor site to another nuclear reactor that is still operating. However, the nuclear reactor operation license issued by the NRC authorizes the nuclear power plant to only possess the amount of SNF necessary to operate that reactor. Therefore, a license modification would be necessary to store additional SNF which would require public hearings at which local opposition would be expected (24). Transferring SNF from a decommissioned reactor to another operating reactor has only been done when both reactors are located at the same site and are owned by the same utility (5).

Risk of Accident

Dry cask storage is considered safer than wet storage because the dry cask storage system is not affected by loss of electricity, coolant, or significant active monitoring. Additionally, SNF in wet storage may be subject to a hydrogen explosion if a loss-of-coolant accident occurs in the reactor. Each dry storage cask holds less SNF and therefore less radioactivity (32 to 68 fuel assemblies per cask) than a storage pool (thousands of fuel assemblies), thereby lessening the consequences of any accident.

A radiological release off-site from a dry storage cask would require that the fuel be aerosolized and that a hole be formed in both the inner and outer shielding that is sufficiently large to allow the aerosolized fuel to escape. Aerosolization of the fuel, which is a ceramic, would require a source of energy, such as a fire.

The NRC estimated that a dry storage cask has a risk of causing a cancer fatality within 10 miles due to a containment failure of 1.8×10^{-12} per year in the first year of operation and 3.2×10^{-14} per year (one fatality ever 31.25 trillion years) for subsequent years. The NRC did not find any risk of a prompt fatality within 1 mile of the dry storage cask (3).

Accelerated Transfer

Since dry cask storage is considered safer than wet pool storage, over 150 community action and environmental groups have advocated for an accelerated transfer from wet storage to dry storage. Accelerating the transfer would decrease the SNF density in the storage pool which would in turn decrease the consequences for any accident in which the pool loses water (13).

Utilities typically wait until the storage pool approaches its capacity before moving the older SNF into dry cask storage because the NRC has determined that pool storage is adequately safe, the license and the regulations allow it, and to avoid what is viewed as an unnecessary cost of moving the fuel to dry storage (5). Reactor operators have stated that the increased risk and expense (billions of dollars) of accelerating the transfer of SNF out of pool storage is not worth the benefits, especially since there is no appreciable increase in safety (13).

The NRC position is that the risk for failure in both wet and dry storage is an acceptable risk and that both types of storage adequately protect the public health and safety, the environment, and security (13). Subsequently there is no urgent safety or security reason for accelerated transfer (28) (61).

Conversely, transferring SNF into the dry storage canister in the storage pool has a risk and accelerating this transfer may increase this risk (13). For example, the risk of an early fatality for a cask drop is 4×10^{-5} for 1 month after reactor shutdown and 7×10^{-8} for 5 years after reactor shutdown for the highest possible radioactivity scenario (2).

Costs

Estimates for the cost of licensing and construction of an onsite dry cask storage facility range from $19 million to $50 million. In addition to licensing and construction costs, costs of containments for storage are also significant. For instant, a storage cask that can store 20 to 30 SNF assemblies from a pressurized water reactor or 60 assemblies from a boiling water reactor costs from $750,000 to $1 million. Further, operating cost for an onsite storage facility is $1 million per year when the reactor is operating and increases to a range of $4.5 million to $8 million when the reactor is decommissioned and the SNF is stranded. And once the site is no longer operational, the cost of transferring SNF from pool storage to a dry storage cask ranges from $1 million to $1.8 million per dry storage canister (13) (4) (23) (62).

Higher Burnup Fuel

Within the last 15 years, utilities have been increasing the burnup rate of nuclear fuel by operating the reactor at a higher power level and extending the time the fuel is in the reactor. Until 2001, the burnup rates typically did not exceed 35,000 megawatt days per metric ton uranium (MWd/MTU). In 2013, the average burnup rate for Pressurized Water Reactors is 51,000 megawatt per metric ton heavy metal (MW/MTHM) and expected to increase up to 55,000 MW/MTHM by 2021; for Boiling Water Reactors the average is 45,000 MW/MTHM in 2013 and not expected to increase to more than 46,000 MW/MTHM in the future. The storage systems for SNF have been developed for the lower burnup rate and thus the increased burnup rate presents additional challenges for long-term storage of SNF. For example, higher burnup fuel emits more heat when removed from the reactor and is expected to require seven years of wet storage before it can be transferred to dry storage (1) (63) (56) (23).

Storage Lifetime Research

Determining the lifetime for the various components of the storage system (spent fuel, cladding, canisters, casks, and concrete shielding) is important since the SNF is expected to be stored indefinitely. Damage to the SNF and its containers may need to be rectified before it can be transported for interim storage or disposal.

Research has been conducted to determine the lifetime of SNF and other components of the dry storage system, mostly for fuel with a burnup below 45,000 MWd/MTU. In 1999 EPRI conducted an inspection, with the assistance by the NRC and DOE, of a SNF assembly (The fuel had a burnup of 35,000 MWd/MTU and was in dry storage for 14 years). The main objective was to inspect for any signs of degradation in the cask and in the spent fuel assembly, especially the Zircaloy cladding. Additional tasks were a visual examination of the cask and of the outer surface of the fuel assembly, check of the concrete pad, radiation survey to test the shielding for degradation, and an analysis of the gas inside the cask for any evidence of outside air having entered the cask or of gaseous fission products. Destructive analysis was also performed on the spent fuel rods.

No evidence of significant degradation was found:

- The gas analysis found no outside air or gaseous fission products inside the cask.
- The O-rings for the cask lid were in good shape.
- No major crud spallation was seen from the surface of the fuel rod.
- All parts of the fuel and dry cask storage system appeared the same in 1999 as

they did in 1984.

The destructive testing showed that the fuel and cladding properties were acceptable for safe storage. In addition, creep was not expected to increase significantly over time since the temperature decreases over time, which reduces stress and pressure (64) (65).

Building upon this inspection, EPRI is the lead contractor in a DOE-sponsored study (Extended Storage Collaboration Program) to research aging effects and mitigation options for long-term storage and subsequent transportation of HLW and SNF. The DOE, the NRC, and the U.S. Nuclear Waste Technical Review Board have completed a technical gap analysis to set the research priorities of this program. The three gaps that have the highest priority are

- Cladding degradation of high burnup fuel (over 50,000 MWd/MTU) due to creep and hydride reorientation,
- Corrosion on the outside surface of the stainless steel welded canister (containing SNF and helium inside), and
- Concrete, used for shielding and structure, degradation.

To address the first priority of high burnup fuel, EPRI plans to use a dry storage cask which is equipped with sensors to monitor the SNF for a period of up to 10 years at the ISFSI at Dominion Virginia Power's North Anna nuclear energy facility (66) (57).

Current Situation in Texas

Texas has four commercial nuclear power plants located at two sites and two universities with research nuclear reactors. The DOE Pantex site is located near Amarillo and it may contain HLW. The DOE dismantles nuclear weapons at this site and is outside the scope of this report.

The two nuclear power plants are relatively young (first one began operation in 1988) and, assuming they both renew their licenses for an additional 20 years, have at least 35 years before initiating decommissioning. One site has a dry cask storage system in use and the other site is expected to use dry storage by 2016. The dry storage systems will be paid for by the federal government. After the reactors are decommissioned, if an interim storage or disposal option is not yet available, the SNF will be stranded and will remain on the site in the dry storage system.

The DOE takes responsibility for the SNF produced in the university research reactors, as it does for all research reactors. Therefore, the universities do not face the same issues of SNF storage and disposal.

Comanche Peak

Comanche Peak Nuclear Power Plant is located at Glen Rose, about 40 miles southwest of Fort Worth. It is operated by Luminant Generation Co., LLC. The plant currently contains two units. Units 1 and 2 are both pressurized water reactors and both are licensed for 3,612 Megawatts thermal. The license for Unit 1 was issued on April 17, 1990 and will expire February 8, 2030 and the license for Unit 2 was issued on April 6, 1993 and will expire February 2, 2033. Both licenses can be renewed for another 20 years.

A license application for two new units (advanced pressurized water reactor) had been submitted to the NRC in September 19, 2008. The projected date for the NRC Commission to make a decision on granting the license is November 2015 (67). However, in November 2013, Luminant Generation Co. suspended its plans to build these new reactors but did not withdraw its application to the NRC (68).

A dry storage cask system of concrete casks stored vertical on a concrete pad was constructed in 2011 and the first SNF was loaded into these casks in 2012 (62).

South Texas Project

The South Texas Project (STP) Nuclear Power Plants are located at Bay City, about 90 miles southwest of Houston and are operated by STP Nuclear Operating Co. STP currently has two licensed units. Units 1 and 2 are both pressurized water reactors and both are licensed for 3,853 megawatts thermal. The license for Unit 1 was issued on March 22, 1988 and will expire August 20, 2027 and for Unit 2 was issued on March 28, 1989 and will expire December 15, 2028. Both licenses can be renewed for another 20 years. On September 20, 2007, STP submitted a license application for two new units (advanced boiling water reactor) (67). The NRC determined that the applicant did not meet foreign ownership requirements and the application review has been indefinitely delayed (69).

In June, 2013, Holtec International announced that it received the contract to build a dry storage system of concrete casks placed vertically for STP with initial loading of SNF in 2016 (70).

Research Reactor at Texas Universities

Texas A&M University at College Station has two reactors: an AGN-201M and a TRIGA Mark I. The AGN-201M has a thermal power rating of 5 W and was purchased by the university in 1957. The TRIGA Mark I has a thermal power rating of 1 MW (71). The University of Texas at Austin has a TRIGA Mark II which can achieve power levels up to 1 MW at steady-state operation or up to 1500 MW for up to 10 milliseconds in pulsing mode operation (72).

Research reactors differ from electricity producing commercial reactors in that the reactor is not operated continuously but only when needed for training or research. Consequently, a nuclear fuel rod could be in the reactor for up to twenty years. Research reactors also have a smaller core size. The volume of spent nuclear fuel stored onsite is considerably lower than the volume stored at commercial nuclear power plants.

The DOE owns the fuel in research reactors and picks up any SNF once contacted by the university. The time that SNF is stored onsite is dependent on the waste collection schedule of when the DOE can have the personnel and equipment ready for pick up.

Safe and secure storage of the SNF is available onsite. Since the DOE takes title of and picks up the SNF, the problem of SNF storage and disposal does not apply to these two universities.

Transportation issues

There are several methods used to transport SNF such as railways, barge, and public roads. In the U.S., over 3,000 shipments of SNF have been transported over a total of 1.7 million miles between 1970 and 2010 (2010 chosen since it is the time of the report referenced). In the course of those 3,000 shipments there were only a total of nine accidents. Further, of the nine accidents, only five involved radioactive material and in none of those accidents was any radioactive material released.

Generally, rail transport is considered to be less expensive than truck transport, but actual cost is difficult to calculate (23). Accident calculations also show that rail transport is safer and is expected to result in fewer accidents (6).

The transportation of the large number of SNF casks being stored at 77 different sites throughout the country will be a complex logistical project that will require time and money. Transporting all of the SNF to a single site (assuming 2,000 metric tons per year) is expected to take over twenty years (13) (23). The DOE estimated that SNF would be accepted over 24 years for the Yucca Mountain repository with up to 10,700 rail shipments (mostly rail scenario) or 53,000 truck (mostly truck scenario) shipments in highway transport (6). PFS expected that one to two trains would arrive each week, with each train carrying two to four shipping casks and each cask containing about 10 MTHM (31).

Requirements for Transportation Casks

The transportation casks must

- Have a strong structural integrity to withstand accidents without releasing radioactive material,
- Provide shielding from radiation, and
- Dissipate the heat emitted by the fuel.

In addition to the requirements listed above a cask must be certified by the NRC for transportation. The certification review and testing of the cask must demonstrate that in an accident the cask will not release any radioactive material, limit radiation doses to acceptable levels, and prevent criticality from occurring. Further, the cask must pass four tests which simulate severe accident scenarios:

- Impact: 30 foot drop onto an unyielding flat surface,
- Puncture: 40 inch drop onto a vertical steel bar,
- Fire: exposure of the entire cask to a fire for 30 minutes, and
- Submersion: immersed under three feet of water and also pressure is applied which is equivalent to 50 feet and 650 feet (only for casks designed to hold over a million Curies of radioactivity) of water (6).

Transportation casks are built to comply with all these requirements by having walls of steel and shielding materials (typically concrete) and a massive lid. To further ensure safety during transport, impact limiters are placed on both ends of the container during transport which absorb impacting forces during an accident. A truck typically carries one to two tons of SNF in a shipment that weighs, when including the weight of the transportation cask, about 25 tons. A rail transportation cask can carry up to 20 tons of SNF and weighs up to 150 tons (28).

To date, NRC has not issued a certificate for a cask to transport the high burnup SNF (13) (4). High burnup SNF may require additional time for cooling or to have fewer SNF assemblies loaded into a cask. Modifications for certified casks to transport high burnup fuel may include a redesign of the heat removal system, the radiation shielding, and the structural support for the SNF assemblies (56).

Dual-Purpose Casks: Storage and Transport

Casks certified for storage are tested and designed for different criteria than casks certified for transport. The NRC regulates the design and construction of the transportation casks under 10 CFR Part 71 and for storage under 10 CFR Part 72.

The development of dual-purpose (both storage and transport) casks began in the late eighties and now only dual-purpose casks can be procured (7). In the U.S. in 2010, about 238 of the 1,242 dry storage casks storing SNF are not dual-purpose casks (23). If transportation standards change, degradation has occurred, or if the fuel has changed from what was certified (such as higher burnup of fuel), then the dual-purpose cask may no longer be certified for transport.

As part of the Yucca Mountain project, the DOE designed a canister that can be used for storage, transport, and disposal to minimize any transferring of SNF from cask to cask. This canister is called the transportation, aging, and disposal (TAD) canister. However, no TAD canisters have been produced commercially (13) (23).

Standardization

The NRC has licensed over 50 different models of dry storage casks manufactured by about a dozen companies. The use of different storage casks and facilities throughout the country has the consequence of increasing transportation cost due to the inability to use standardized equipment such as the grappling hook or other equipment that needs to be modified to fit the various sizes of the transport casks. The DOE estimated that to move the stranded SNF at the seven sites in four years would require 20 NRC-certified transportation casks since the SNF is stored in six different types of casks and each cask type requires a specific transportation cask system (24).

Planning and Infrastructure

Transportation planning may take up to 10 years to determine agreed-upon transportation routes and to establish safety and security procedures (1). Required tasks include coordinating federal, state, and local emergency response plans along the expected transport routes, training first responders, designing and building infrastructure and equipment, and developing inspection protocols. The DOE has considerable experience in transportation planning and implementation with one example being the shipments of transuranic waste to the Waste Isolation Pilot Plant in New Mexico.

Infrastructure and equipment required for large scale shipments of the SNF in this country are not available and will need to be designed, fabricated, tested and licensed. The Association of American Railroads requires the rail cars to have a special safety feature to transport SNF and it is expected to take 5 to 7 years to design and develop rail cars with these features (4). The locomotives used to pull these rail cars also need special features, which had been designed and tested by PFS (23). The number of certified casks available for SNF transport is few and are mainly for use with trucks (4).

Another transportation challenge is to build rail spurs to the 72 commercial nuclear power plant sites and obtain permission to ship the SNF on the rail network. The DOE, in their investigation of developing a rail shipment scheme for the Yucca Mountain repository, determined that 25 of the commercial nuclear power plant sites had no direct rail access (12 had rail access within 10 road miles, 9 within 50 miles, and 4 within 200 miles) but a majority of them could use barge transport to access a port-rail facility (23).

Additionally, the reactor operators will need to modify the infrastructure at the storage site and procure dedicated equipment for moving the casks off the reactor sites (4).

Safety and Security

SNF is more vulnerable to sabotage or accidents during transportation compared to storage since fewer security personnel and fewer engineered barriers are available. Consequences due to sabotage or accidents are also higher during transport since the waste may be near population centers (60).

According to DOE calculations, the accident probability for a SNF shipment by rail is 1 in 10,000 and by truck is 1 in 1,000. Over the 24 years of shipping SNF to the repository, the number of expected accidents is one if shipments are mostly by rail (10,700 rail shipments) or 53 if shipments are predominately by truck (53,000 truck shipments). Further, the probability that an accident would result in even a small release of radioactive material or that the radiation shielding is damaged resulting in a low radiation exposure to the public in the nearby vicinity is 0.0001 (0.01%, 1 in 10,000). Therefore, the probability of the public being exposed to radiation in an accident over 24 years is 0.01% for the mostly rail shipment scenario and 0.53% for the mostly truck shipment scenario (6).

The "maximum reasonably foreseeable accident scenario" for truck transport in which radioactive material is released in a urbanized area results in a 0.15% increase in the probability of getting cancer for the maximum exposed individual and has a probability of occurring of 0.000023% (occurs once every 4.3 million years). For transport by rail, the "maximum reasonably foreseeable accident scenario" results in an increase cancer risk of 1.5% to the maximum exposed individual and has a probability of 0.000028%

(occurs once every 3.6 million years). For the 24 years of normal transportation (no accidents), the increase in cancer risk for the maximum exposed individual for the mostly truck scenario, which would be a truck stop worker, is 0.1% and in the mostly rail scenario, someone who lives next to a rail stop, is 0.01%. These increases in cancer risk are insignificant when compared to the national average probability of cancer of about 25% (6).

The NRC is currently modifying the security rules for transporting SNF and other high activity radioactive materials. Proposed changes include advance planning and coordination with states, increased notifications and communications, continuous and active shipment monitoring, armed escorts during the entire transport (currently it is required only in highly populated areas), and background investigations of personnel who have access to information about security and safeguards of the shipment (4).

Analysis of the Available Options

The federal government assumed responsibility for the disposal of HLW to promote nuclear energy while protecting the public and the environment. The NRC regulates nuclear power plants and the management of HLW. Under the NWPA, the DOE was to take title to and dispose of the SNF stored at the commercial nuclear power plants in 1998 but was unable to fulfill this requirement due to the lack of a repository successfully being built at Yucca Mountain. Attempts for centralized interim storage of the SNF, both by the federal government and by private companies, have also failed. Reprocessing of the SNF, though done in several other nations, is not a viable option in the United States. The current situation is that SNF is stored onsite at the nuclear power plant sites and will continue to be stored onsite indefinitely.

Reprocessing

Reprocessing of SNF is technologically feasible and would extend the energy potential in nuclear fuel and decrease the volume and radioactivity of HLW. The question on whether commercial reprocessing should be developed in the United States is a part of the much larger question on the future of nuclear power in this country, which is outside the scope of this report.

Reprocessing is currently not economical compared to the one-time use of nuclear fuel and thus there is no cost driver to build commercial reprocessing capability. Commercial reprocessing will need significant funding by the DOE to be viable. However, the current administration does not support reprocessing. The long time required to develop commercial reprocessing capability is longer than the average time in which political support for reprocessing changes which has effectively stalled any attempt to build a commercial reprocessing facility.

Even if a commercial reprocessing facility was to be built, it would not be available until 2030 to 2040 (5) (23). Therefore, near-term HLW management policies should not include the possibility of reprocessing. However, reprocessing technology can change the view of SNF as waste to that of a valuable energy resource. Advances in technology or changes in policy or economics could feasibly favor the development of commercial reprocessing in the future and should not be ruled out. Consequently, SNF storage and disposal facilities should be designed so that SNF can be easily retrieved in case reprocessing becomes available in the U.S.

Onsite Storage

NRC has determined that the current system of storing SNF in a dense configuration in the storage pool inside the reactor building and in a dry storage cask system on the site of the nuclear power plant is within acceptable safety limits. Studies have indicated that SNF can be safely stored in this manner for 120 years; however, these studies have some uncertainty concerning the higher burnup fuel that recently has been discharged from the reactors.

The nuclear power plants in Texas are relatively young compared to other reactors in the United States and are not expected to shut down for over 3 decades. If the DOE is not able to take title to the SNF in three to four decades, then the SNF will remain onsite in dry storage even though the reactor facility will be decommissioned.

Onsite storage for decades is currently the only available option for SNF management, which was not envisioned in the initial plans of nuclear power. Although considered safe, it should not be considered an adequate solution. A nuclear power plant has an operating life of up to 60 years and then is decommissioned. When a nuclear power plant is decommissioned, the SNF remains onsite with nowhere to go, increasing the cost of maintaining and guarding this waste (paid for by U.S. tax payers) and preventing the full site to be returned to unlimited use.

The lack of an alternative to onsite indefinite storage is hindering nuclear energy from being fairly considered as an energy option and is an embarrassment to this country's reputation for its capability to handle its waste. Every decade that SNF remains in storage increases the uncertainty that the fuel can be safely transported and potentially increases the risk and cost of transportation and disposal.

A solution for onsite indefinite storage of SNF is clearly needed and should not be delayed any further. Since the federal government has assumed responsibility for regulating SNF and for its final disposal, it will need to be the primary mover to achieve a permanent solution to managing SNF.

Geologic Repository

The federal government needs to either continue with the license application for the Yucca Mountain repository or immediately enact new legislation to authorize the site selection process for one or more new repositories.

The main benefit of continuing with the Yucca Mountain repository is that the site has already been characterized and the license application submitted to the NRC. However, attempting to rely solely on the Yucca Mountain repository makes the future of SNF management highly uncertain since the license review and repository construction could be continually delayed with the end result being more wasted time and money. To illustrate, political and legal battles have already delayed the planned opening of the repository from 1998 to the current day.

Even if the Yucca Mountain facility is built, the volume of SNF has increased beyond the planned disposal volume of this repository. The NWPA mandates that the Yucca Mountain repository is to have a disposal capacity of 70,000 MTHM, of which 63,000 MTHM will be from commercial reactors. An additional 40,000 MTHM of disposal capacity is projected to be needed if the current trend of renewing reactor licenses from 40 to 60 years continues (23).

Either a second repository is needed or the disposal capacity of Yucca Mountain needs to be enlarged. Either of these options requires Congressional action.

Further, the site selection and the design of the geologic repository needs to be undertaken in a manner that is free from political and legal interference and the suggestions in the Blue Ribbon Committee's report is a good starting point for Congress to begin the debate on the necessary revision to the NWPA.

Centralized Interim Storage

Storage of SNF would still be required for decades even if definite plans to construct a geologic repository were implemented. DOE estimates that:

- A geologic repository would not open until 2048 if the licensing and construction efforts began immediately (1),
- Interim storage would still be needed for 36 years after a geologic repository was completed (5), and
- Twenty-four years would be needed to transport all of the SNF to disposal (6).

The SNF will still require decades of storage before disposal can become available but this storage should not be at the nuclear power plant sites. One or more centralized storage facilities should be constructed so that SNF can be moved off of the nuclear power plant sites. The Blue Ribbon Committee recommended "prompt" efforts to develop one or more consolidated storage facilities concurrently with one or more geological disposal facilities.

Constructing only a disposal facility without one or more centralized interim storage sites should not be considered since a centralized interim storage facility would

- Reduce the cost (storage in one site verses storage at 77 sites),
- Increase safety and security,
- Allow the DOE to take title to the SNF sooner (by two to three decades), and
- Help the DOE to optimize the thermal loading of the HLW into the repository.

The annual operation costs of dry storage for SNF at the 72 commercial nuclear power plant sites will be greater than the annual costs of storing this SNF at a centralized interim storage site (assuming that reactors operate for 60 years) by 2030 (23).

On the other side, arguments against centralized interim storage are that the risk of transporting the SNF is greater than the benefits of centralized interim storage, the SNF would be transported twice — from the reactor to the storage site and from the storage site to the disposal site — which would result in greater cost and worker exposures, and the interim storage may become a permanent solution since pressure for a geological repository would diminished if the DOE takes title to all of the SNF while in storage.

Risk calculations for SNF transport show that the risk is not significant and that over 3,000 shipments of SNF have already been transported over a total of 1.7 million miles with no accidents involving release of radioactive material (23).

According to the BRC recommendations, public perception and concern about interim storage becoming the de facto permanent solution will be significantly reduced if the interim storage facility is built concurrent to efforts to site and build a geologic repository.

The DOE estimated that if the licensing and construction efforts began immediately, a pilot interim storage facility could be operational by 2021, a larger interim storage facility by 2025, and a geologic repository by 2048 (1). EPRI estimates that six years would be needed to develop an away-from-reactor ISFSI including designing the facility, the license application process, and construction, assuming the dry storage system is one that the NRC has already certified, no outside interferences during the NRC hearing process delay the licensing process, and the application is of good quality (7).

A centralized interim storage (or away-from-reactor) facility would require a site specific license under 10 CFR §72 for 40 years initially and an option to renew for another 40 years. The license application would not be able to use the generic environmental impact statement from the NRC waste confidence rule, the waste confidence rule, or the general license found in 10 CFR part 72 subpart K (38).

Private or Government Ownership or Operation of Interim Storage Site

Private off-site storage of the SNF from multiple reactors was attempted in Utah by PFS but local and state opposition delayed the start of construction for 15 years until PFS cancelled the project. Arguments against the PFS facility included:

- Transportation of the waste was seen as an unnecessary risk,
- That long-term storage may become de facto permanent,
- A private storage facility would derail the national HLW policy (concern that private industry may direct national waste policy),
- Safety of long-term storage,
- The operator of the facility would have minimal liability, and
- A feeling that it was unfair to Utah to have to store most of the nation's SNF (73).

Any attempt by a private corporation to site an interim centralized facility would probably face the same opposition. Therefore, finding a site that has local and state support would greatly enhance the chance of a private centralized interim storage site being successfully sited and constructed. The successful implementation of siting and constructing a geologic repository by the federal government would also enhance the probability of an interim storage facility being constructed. The NRC has already determined that the transportation and long-term safety risks are not significant.

It is important to note, however, that one problem with a private centralized interim storage site is that the nuclear power plants would still have title to the SNF and would have to take back the waste if the storage facility closes without a repository available. If the nuclear power plant has been decommissioned by this time, the waste generator would not be able to take back the waste. Stranded SNF at a closed centralized storage facility is one of the worries of those who oppose the building of a private centralized storage facility and was the reason given by the Bureau of Indian Affairs for rejecting the Goshute's lease with PFS (32).

The failure of the DOE to take title to the SNF in 1998 and the high probability that the DOE will not be able to take title to SNF in the next ten to twenty years makes the successful siting and construction of a private centralized interim storage facility highly uncertain and may be too uncertain for a private company to attempt. However, an interim storage facility owned by the federal government would allow the DOE to take title to the SNF stored in it, which would increase the probability that such a facility could be constructed. DOE often uses private entities to operate its national laboratories and other facilities so a DOE owned interim storage facility could conceivable be operated by the private sector.

Siting a Disposal or Storage Facility

Building the centralized storage site on federal land has been suggested, especially at or near one of the national laboratories that perform nuclear energy research so that the nuclear infrastructure (such as skilled and experienced personnel, rail transportation, and security services) would already be present. However, political opposition at the local and state level stopped the plan to build the MRS facility at Oak Ridge National Laboratory, so such a plan would not be a short cut through the siting process.

Another option to take advantage of available infrastructure and experience would be to build the storage site at one or more operating commercial nuclear power reactors. The facility would need to be part of a competitive selection process or local and state opposition and the subsequent political pressure would be expected to be strong.

Expanding the Waste Isolation Project Plant (WIPP) from disposing of only transuranic waste to high level waste has also been suggested. The geology of the WIPP plant has been demonstrated to be suitable for very long-term waste disposal. However, during the siting process of WIPP, the DOE agreed to not expand the mission of the WIPP to include other types of waste. Any attempt to dispose of HLW at WIPP will need to be part of a competitive and fair siting process.

Another option is to reconsider the seven communities who volunteered for the MRS or the eleven communities who volunteered to host the Global Nuclear Energy Partnership facilities. State opposition prevented any of the MRS sites from being characterized, so state as well as local support is necessary. Additionally, the DOE states that "that local willingness and support for a site initially does not ensure continued support for the facility during the long timeframe needed to license and build such a facility" (24).

Any federal program to manage HLW (disposal, storage, or reprocessing) needs to be established in a manner that reduces the uncertainty due to changing prevailing political opinions and minimizes local and state opposition through stakeholder meetings, financial incentives, and a process that is considered fair and technically rigorous. Otherwise, the effort to license and build these facilities may result in nothing but wasted time and wasted money like the Yucca Mountain repository, the PFS storage facility, or the MRS facility. However, successfully sited and built radioactive waste disposal facilities also exist such as WIPP in New Mexico for transuranic waste and the Low Level Radioactive Waste Disposal Facility in Texas. The siting and construction of a HLW storage or disposal facility is therefore feasible if the proper siting methodology is used.

An important recommendation of the Blue Ribbon Committee is that Congress should "authorize a new consent-based process to be used for selecting and evaluating sites and licensing consolidated storage and disposal facilities in the future, similar to the process established in the expired Nuclear Waste Negotiator provisions of the Act" (4). The siting options discussed above, though opposed and ultimately rejected in the past, may be considered favorably in the future if such a consent-based siting process is employed.

State governments are communicating with the federal government that they want to be considered partners with the federal government and have a clear decision-making voice on the siting, building, and operation of any HLW storage or disposal facility within their borders. Past experience has shown that both local and state support is necessary to successfully site a HLW disposal or storage facility. The WIPP facility is an example of how public support for the project was generated by the DOE working together with the state government, such as obtaining permits from the EPA and the state of New Mexico instead of self-regulating the facility. Past experience has shown that siting a radioactive waste facility often fails when the state strongly opposes it even though in nearly every case the affected local governments strongly supported the facility because of the jobs created and as a means of economic growth for the local area (42).

Conclusion

Onsite storage of SNF for decades is currently the only available option for commercial nuclear power plants, which was not envisioned in the initial plans of nuclear power. Although considered safe, it is not an adequate solution. A nuclear power plant typically operates for 60 years and then is closed and decommissioned. The SNF stored onsite remains at the site and the full site cannot be released for unrestricted use. A solution for onsite indefinite storage of SNF is clearly needed and should not be further delayed.

Since the federal government assumed responsibility for regulating and disposal of SNF, it will need to be the primary driver in finding a permanent solution for managing SNF. Congress needs to either fund the license review of the Yucca Mountain geologic repository so that it could be constructed or change the NWPA so that a new site selection process for one or two geologic repositories can begin. Additionally, Congress needs to amend the NWPA to authorize the construction of centralized interim storage facilities in which the DOE takes title to the stored SNF even if DOE does not actually operate the facility. DOE often uses private entities to operate its national laboratories and other facilities so a DOE owned interim storage facility could conceivable be operated by the private sector. In fact the consent-based siting recommended by the BRC make a public-private partnership approach even more attractive. It has already been done with great success where other approaches have repeatedly failed.

Because many earlier attempts to select a site for a repository or storage facility for SNF have failed due to local and state opposition. Selecting a site for and constructing an interim storage facility would have a greater chance for success if the site has local and state support and the federal program to site and build a geologic repository is also successful. Any federal and/or private program to store or dispose of SNF needs to be established in a manner that reduces the uncertainty due to changing prevailing political opinions and minimizes local and state opposition through stakeholder meetings, finding volunteer communities, financial incentives, giving the state a clear decision-making voice on the siting, building, and operation of the facility within their borders, and a process that is considered fair and technically rigorous.

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