THE CAPABILITY FOR THE SAFE INTERIM STORAGE OF SPENT FUEL

July 7, 1980

Prepared for

Utility Nuclear Waste Management Group

and

Edison Electric Institute

(Document 4 of 4)

Prepared by:

Ray Lambert
C. C. Herrington
General Electric Company

James Haley
Westinghouse Electric Corp.

Jay E. Silberg
Shaw, Pittman, Potts & Trowbridge

TABLE OF CONTENTS

THE CAPABILITY FOR THE SAFE INTERIM STORAGE OF SPENT FUEL

I. Introduction

This paper, prepared as a part of the UNWMG-EEI Statement of Position, is intended to complement the other portions of the UNWMG-EEI Statement - "The Capability for Disposing of Spent Fuel or High-level Waste Safely" and "Long-term Safety of Nuclear Waste Disposal: A Basis for Confidence". This paper demonstrates that spent fuel can be safely stored until such time as disposal becomes available and that there is reasonable assurance that interim storage facilities will be available when needed.

II. Statement of Issues and Summary Conclusion

The major issue concerning the interim storage of spent fuel* from nuclear reactors is whether such spent fuel can be safely stored at reactor sites or at other locations until such time as facilities for the off-site disposition of such fuel are available. There is no technical reason why such a facility could not be in operation by 1995. However, since we do not know with certainty when off-site disposal or re-processing facilities will be available, it is appropriate to examine the range of time periods for which spent fuel may be

---

* The scope of this proceeding is limited to the disposal of spent fuel as waste. UNWMG-EEI believes, however, that a more desirable approach is the reprocessing of spent fuel to reclaim the energy resources contained therein, and solidification and disposal of the remaining fission product waste.

safely stored. The analysis will consider the following questions:

- whether spent fuel can be safely stored on-site past the expiration of existing facility licenses
- whether spent fuel can be safely stored (on-site or off-site) until off-site disposal is available
- whether on-site and off-site storage of spent fuel will be available when needed.

Based on our analysis, we have reached the conclusion that spent fuel storage in water filled basins--either in the reactor's spent fuel pool, a separate at-reactor pool, or an away-from-reactor facility--is a safe, proven technology capable of storing spent LWR fuel for periods of many decades. Other options, such as dry storage, are likely to provide the capability to safely store spent fuel for even longer periods. Spent fuel storage is now available and there is reasonable assurance that it will continue to be available to the degree required to handle the spent fuel being generated from reactors in operation, under construction and planned.

III. General Description of Present Storage Technology

Spent fuel storage practice to date has been dominated by water basin storage. The technology is the same whether the fuel is stored in a reactor basin, a separate facility at the reactor site, or an away-from-reactor pool. A general description of basin storage follows.

A. Water basin storage

A water basin storage system consists of: (1) a water-filled reinforced concrete basin (or swimming pool-like structure) typically lined with stainless steel; (2) a rack or rack-and-basket system for supporting the fuel; (3) cranes and material-handling equipment for handling the fuel and baskets; (4) a heat exchanger for controlling the water temperature; and (5) a clean-up system for controlling the water purity.

The components of the water basin storage system involve straightforward, well-known, and well-developed techniques and technologies in their design, construction and implementation. These technologies have been applied in industry for decades and are neither new, exotic nor untried.

A spent fuel storage basin is also relatively small. For example, even with less than maximum packing densities, water basin storage for the forty year lifetime of an 1000 megawatt reactor occupies only about 3500 square feet of pool floor area.*

Largely as a result of the attractiveness of water as a storage medium and familiarity with the technologies involved,

---

* Based on 1200 MTU per lifetime and unpoisoned storage at approximately 0.34 MTU/ft^2.

water basin storage is currently the only storage means in wide-spread use.

B. Methods of expanding existing storage capacity

Most reactors that are currently in operation were designed with spent fuel pools having relatively limited storage capacity, typically one full core plus one discharge.[1] The capacity of most of the pools at reactors currently in operation has already been expanded, within the physical confines of the existing pool. Some reactors are on their second round of expansions. Basically, three different methods have been used to increase the capacity of existing pools: additional spent fuel storage racks, racks using closer spacing, and "poisoned" racks. In some pools, there was room simply to add more racks of the same design as the original racks.[2] The most common method used to date involves replacing the original racks with ones in which the spent fuel assemblies are stored closer together ("high density racks").[3] In achieving closer spacing of spent fuel, storage system designs must still assure that the spent fuel remains subcritical by a safe margin. As an example, center-to-center PWR spent fuel spacing can be reduced from about 20 inches to about 12-14 inches while still meeting all criticality safety requirements.[4] Even closer spacing (and therefore greater storage capacity) can be achieved with so-called "poison" racks, that is racks which include neutron-absorbing materials such as boron carbide.[5] Incorporation of neutron-absorbing material into system hardware permits greater compaction, with spent fuel spacing of 11-12 inches achievable for PWR fuel.[6]

C. Historical Background

From the very first nuclear reactors built by the Government in 1943, irradiated fuel has been discharged into water basins and stored there until it was reprocessed. The first commercial-scale power reactors, Shippingport (1957) and Dresden (1960), and all commercial light water reactors since then, have utilized water basins.[7]

The designers and operators of early power reactors planned on the prompt reprocessing of spent fuel. Spent fuel pools at reactors were typically sized to store about one and a third cores.[8] Much of the fuel discharged from the early U. S. test and power reactors was in fact reprocessed at the Nuclear Fuels Services reprocessing plant at West Valley, N.Y. and at government reprocessing facilities.[9] By about 1975, however, the Nuclear Fuels Services plant had closed and it was becoming apparent that other reprocessing facilities would not be available on schedule. Licensing delays due to the GESMO proceedings made it apparent during this period that reprocessing facilities in the advanced stages of construction and design would not be available as scheduled. As a result, utilities began the process of expanding their on-site storage capacity.

In addition to spent fuel storage at reactors, water basin storage pools were designed and constructed as a part of reprocessing facilities. The Nuclear Fuel Services reprocessing plant at West Valley, N. Y., which operated from 1967 to 1972, has a spent fuel storage capacity of about 250 MTU, with approximately 165 MTU now in storage.[10] General Electric's Morris Operation has a 700 MTU capacity storage pool with about 31[illegible] MTU now in storage.[11] Unlike Morris and West Valley, both of which are currently licensed as spent fuel storage facilities, the spent fuel storage pool at the Allied-General Nuclear Services reprocessing plant in Barnwell, South Carolina, although constructed is not now licensed. The Barnwell pool has a storage capacity of 400 MTU.[12]

Government sites where nuclear activities are conducted also have water basin fuel storage facilities. These include the Hanford, Idaho and Savannah River installations.[13]

D. Experience With Extended Storage of Spent Fuel

The experience with extended storage of spent fuel has been excellent. The majority of the earliest discharged LWR fuel is no longer in storage, having already been reprocessed. However, a small number of assemblies have been stored for a period of some twenty years, with no apparent degradation due to storage. Some Zircaloy clad PWR fuel has been in water basin storage since 1959. (Zircaloy cladding is used in almost all light water reactor fuel). Some stainless steel clad BWR fuel was stored from 1963 to 1975 when it was reprocessed. Stainless steel clad PWR fuel has been stored since 1970.

The maximum residence times spent fuel in pool storage is summarized in Table 1.[14]

TABLE 1. Maximum Fuel Bundle Residence Times in Pool Storage

No. of Bundles	Cladding	Reactor	Date in Pool Storage	Location	Burnup,[c] MWd/MTU Maximum
1[a]	Zircaloy-2	PWR	1959	ECF/Idaho	6,000
25	Zircaloy-2	PHW	1963	NRU/AECL	10,000
47	Stainless	PWR	1970	GE/Morris	19,900
60	Stainless	BWR	1963[b]	SRP/So. Car.	10,000

(a) Two additional Shippingport bundles are in storage at ECF, one discharged in 1961 and one discharged in 1964.

(b) Reprocessed in 1975.

(c) Applies to burnup on peak bundles.

In addition, at least nine Zircaloy-clad fuel bundles from the Canadian NPD reactor have been in water storage since 1962 (although these have little or no burnup),[15] and eight bundles loaded in the NPD reactor in 1963 are still in core and intact. The experience for the storage of high burn-up fuel is summarized in Table 2.[16]

TABLE 2. Maximum Fuel Burnup on Stored Commercial Fuel

Cladding	Reactor	Burnup[(a)] MWd/MTU Maximum	Reactor Discharge Date
Zircaloy-2	BWR	25,000	1974
Zircaloy-4	PWR	33,160	1976
Stainless Steel	PWR	33,200	1973
Stainless Steel	BWR	22,000	1975

[(a)] Applies to burnup on peak bundle

The favorable performance of spent fuel stored in water basins has been confirmed by observation and analysis. No degradation has been observed in commercial power reactor fuel. This is based upon a survey of basin operators representing some 20 U. S. pools.[17] Canadian experience, including occasional examination during 17 years of storage, has indicated no evidence of significant corrosion or other chemical degradation.[18] Even where the uranium oxide pellets were exposed to pool water as a result of prior fuel assembly damage, the pellets have been inert to pool water, a conclusion also demonstrated in laboratory studies.[19]

Further experience concerning the ability of spent fuel to withstand extended water basin storage includes metallurgical examination of Canadian Zircaloy clad fuel after 11 years of pool storage, metallurgical examination of Zircaloy clad PWR and BWR high burn-up fuel after five and six years in pool storage, return of Canadian fuel bundles to a reactor after 10 years of pool storage, and periodic hot cell examination of high burn-up PWR and BWR bundles over 6 years of pool storage at the WAK Fuel Reprocessing Plant in Germany. Favorable experience in other countries with Zircaloy clad fuel includes United Kingdom, 13 years; Belgium, 12 years; Japan, 11 years; Norway, 11 years; West Germany, 9 years; and Sweden, 7 years.[20]

The only fuel failures which have occurred in spent fuel pools involved types of fuel and failure mechanisms not found in U. S. commercial reactors. One involved Zircaloy clad metallic uranium fuel from the Hanford N-Reactor. The cladding was damaged in the N-Reactor's fuel discharge system (which bears no resemblance to that of commercial reactors) and degradation was caused by reaction between the pool water and the metallic uranium. (Metallic uranium fuel is not used in commercial power reactors). The other instance involved gas-cooled reactor stainless steel fuel cladding, exposed to temperatures in the reactor sufficient to cause sensitization. This latter instance is likewise irrelevant to commercial spent fuel since the temperatures involved are not experienced by fuel in boiling or pressurized water reactors.[21]

The conclusions reached by several researchers on the historic experience all affirm the ability of spent fuel to withstand extended periods of storage in water basins.

- "All the information available suggests that bundles may be kept safely in water for very long times; 50 to 100 years under water should not significantly affect their integrity."[22]
- "Three specific conclusions may be drawn from the current examinations:
  1. No deterioration, either by corrosion or mechanical damage, has occurred during 16 years of storage in water.
  2. There has been no additional release of fission products from the UO_2 matrix during 11 years of storage in water.
  3. No fission product induced stress-corrosion cracking is anticipated during storage at temperatures below 373K.

  These lead to the general conclusion that all evidence to date indicates that fuel can be stored in water for at least 50 years."[23]
- "Pool technologists contacted in the spent fuel survey included operators of pools in the U. S., Canada, the U. K., and the FRG.

> Observations are based on Zircaloy-clad fuel with pool residence up to 19 yr and stainless-steel clad fuel with residence up to 12 yr. None of the pool operators has seen evidence that spent water reactor fuel is degrading in storage pools. These observations are based principally on visual inspection and radiation monitoring of pool water, but are reinforced by some nondestructive and metallographic evidence and by assessments of potential corrosion mechanisms. Degradation at cladding defects also does not appear to be significant for the sintered uranium oxide fuel."[24]

IV. Magnitude of Present Storage Capacity and Projections of Need

The ability to store spent fuel on an interim basis until such time as off-site disposal is available depends on the existing inventory of spent fuel, the rate at which spent fuel is being discharged from reactors, the available storage capacity, and the capability for adding to that capacity.

A large number of studies have been made over the past four years to assess the need for future spent fuel storage capacity. Compared to earlier estimates, the most recent studies show significantly greater on-site storage capabilities based on updated assessments of utility on-site expansion plans and limited opportunities for transshipment between reactor sites. Other studies show somewhat different results, particularly in the need to ship to away-from-reactor facilities. While the studies differ on the amount of AFR capacity needed, all agree that the capability exists for most of the spent fuel discharged from U.S. commercial power reactors to be stored on-site and that some AFR capacity will be needed. This is shown by data from recent DOE studies [25,26] and from a study by the General Accounting Office.[27]

TABLE 3. Spent Fuel Discharges and AFR Requirements

Year	Cumulative Amount Discharged (MTU)	Cumulative AFR Requirements (MTU)			
		DOE Upper Bound	DOE Planning Base	DOE Lower Bound	GAO Estimate
1981	9,102	210	186	22	29
1982	10,900	334	280	97	74
1983	13,103	617	377	171	152
1984	15,740	962	529	233	192
1985	18,727	1457	755	309	318
1986	22,312	2238	1047	385	542
1987	26,202	3119	1491	465	911
1988	30,425	4091	1985	556	1433
1989	34,836	5147	2532	899	-
1990	39,368	6485	3277	1586	-
1991	44,105	8080	4271	2367	-
1992	48,965	10,061	5534	3219	-
1993	53,894	12,472	7013	4375	-
1995	63,901	17,980	10,792	-	-

One major difference between GAO and DOE estimates is that GAO assumes transshipment and DOE does not. A study by the Natural Resources Defense Council* found the need for AFR capacity starting in 1985.[28] All studies agree that the vast majority of spent fuel will be stored by utilities in the reactor pools. Particularly for the more recently designed reactors, a substantial portion of the lifetime spent fuel discharges will be capable of being stored on-site.

V. Methods for Meeting Storage Needs

As discussed above, the primary method for storing spent fuel has been, and will continue to be, on-site storage in reactor spent fuel pools. The primary techniques for increasing existing storage capacities have also been described. In some cases, "second round" modifications of reactor spent fuel pools have been applied for and granted.**

An alternative to reracking existing pools in order to meet storage needs is the so-called "at-reactor site" spent fuel storage facility, an independent spent fuel pool located at the same site as the reactor. This type of facility has been selected by the Tennessee Valley Authority to meet its

---

* The NRDC study did not include the needs of Duke Power Company's Oconee units, since NRDC is an intervenor in the NRC proceeding and is seeking to block the proposed transshipment of spent fuel.

** For example, the Zion, Prairie Island and Point Beach facilities have undertaken, or are awaiting approval for, second round expansions.

storage needs.[29,30] As envisioned by TVA, this storage scheme would involve the construction of an independent storage facility at each nuclear power plant site or the sharing of such a facility for reactor sites which are close together.[31]

Another alternative is the use of away-from-reactor spent fuel storage pools (AFR's). As discussed above, three such commercial pools exist (Morris, West Valley and Barnwell), with the first two already licensed and storing spent fuel. All of these facilities appear to be capable of expansion beyond their present capacity by reracking:[32]

Facility	Present Capacity (MTU)	Capacity with Reracking (MTU)
Barnwell	400	1750
Morris	700	1100
West Valley	250	1500
Total	1350	4350

This capacity could be further expanded by construction of new pools at these facilities. Construction of new AFR's providing storage space in excess of several thousand tons (MTU) of spent fuel is clearly feasible.[33]

In addition to these techniques, other methods could be available to increase storage capacity in existing pools, or to provide for greater storage capacity in new pools. In some pools, fuel could be stored in two tiers ("double tiering"), thus nearly doubling the storage capacity. The ability to utilize this technique depends upon the depth of basin and the structural capabilities of the pool.[34] A second method involves the disassembly of the fuel bundles and the storage of the individual fuel rods in a closer array within a canister. Studies have identified no safety or environmental issues which would preclude its licensing. If implemented, this technique could increase storage by up to a factor of two.[35, 36]

A final possibility for increasing the capacity for spent fuel storage is the construction of dry storage facilities. Spent fuel which has aged sufficiently may be stored in individual canisters with cooling by natural convection or in a "convection vault", with natural convection or forced cooling.* Six concrete canisters are now in operation in Canada, four with spent fuel and two with electric heaters. Operation has been completely successful. Spent fuel placed in canisters in 1975 remains there, with no defects detected.[37] Spent fuel from the Peach Bottom 1 and Rover gas-cooled reactors and the blanket subassemblies from the Fermi 1 breeder reactor are in dry storage at the Idaho National Engineering Laboratory (INEL). The earliest dry stored fuel at INEL has been in place since 1971.[38] In the United Kingdom, irradiated Magnox fuel from the Wylfa reactor has been in dry storage since April

---

* NRC reports preliminary studies showing that about five years of water basin storage provides sufficient decay to allow air cooling. Ref. 3, Vol. 1, p. 3-9.

1979.[39] As a part of the DOE's Spent Fuel Handling and Packaging Program, started in 1977 and currently in progress at the E-MAD Facility at the Nevada Test Site, an encapsulated LWR fuel assembly has been in a concrete sealed storage cask since December, 1978, and two encapsulated fuel assemblies have been in below ground drywells since January, 1979.[40] NRC has concluded that the dry storage concept appears feasible for U. S. spent fuel.[41]

VI. Technical Considerations on Ability to Store Spent Fuel for Extended Periods

A. General Introduction

The technical principles for meeting the functional and regulatory requirements of a spent fuel storage system are straightforward and proven by over 30 years experience in operation and control of nuclear facilities. Major development and test programs are not required to provide safe storage capabilities although on-going development is proceeding to further improve storage efficiencies.

The storage of spent fuel is best characterized by its inactivity. There is little stored energy in the fuel or storage system to act as a driving force. The rate of fuel decay heat generation is relatively low compared to heat generation during power operation, and decreases rapidly with fission product decay after removal from the reactor core. In short, the storage system is a benign environment, particularly in comparison with the pre-storage power generation environment.

B. Storage system stability

In comparison to the elevated temperatures and pressures that exist in the operating power reactor, the spent fuel storage environment is one of low energy content.

Pool storage conditions for spent fuel are dramatically different from those in the reactor. Bulk water temperatures in the pool are typically in the 20°-50°C range; no pool surveyed had operated above 50°C although operating specifications allowed higher limits, in some cases up to 100°C[42]. This compares to the 270°-300°C in-reactor temperature for boiling water reactors and 320°-340°C for pressurized water reactors. Peak centerline fuel temperatures for fuel in water storage is about 100°C compared with 1200°-1350°C while the fuel is in the reactor. Cladding surface temperature in the spent fuel pool is 30° to 60°C, while it ranges from 340° to 400°C in the reactor. Other parameters show similar differences.[43] Unlike the reactor conditions, pressure in the spent fuel pool is atmospheric and water movements are gentle.

No credible mechanisms for rapid change -

The influence of the large volume of water in a water basin system provides a moderating environment that precludes rapid change of storage conditions. Typical pool volumes may range from 250,000 to 830,000 gallons.[44] The large volumes of water assure that any credible failures would only cause slow temperature increases.[45] An extended cooling period for spent fuel in a water basin prior to placement into dry storage would result in low heat generation rates in the dry storage system.

Adequate time to respond -

If some presently unidentified mechanism should arise that could allow radioactive material to escape from the spent fuel storage system, its genesis can be expected to be gradual. Such low energy systems do not undergo rapid changes. Available instrumentation and monitoring programs assure that adequate time would be available for identification and development of remedial action without subjecting plant personnel or the public to significant risk.[46] Remedial actions could include encapsulation or placement in spent fuel storage casks.

C. Fuel Parameters

Diminishing hazard potential -

After reactor fuel is discharged, it continues to generate heat from the decay of fission products. The amount of decay heat generated, however, decreases continuously. The initial decrease is very rapid because many of the short half-life nuclides are totally expended in the early cooling period. About 97% of the radioactive decay energy in a fuel assembly is dissipated in the first month after reactor shutdown.[47] The overall result is that the heat generation rate diminishes and therefore the margin of safety for the storage system increases with time in storage. After only a few weeks of pool cooling, the exterior surface temperature and interior cladding temperature are only about 10°C above the bulk water temperature in the pool (30°-60°C) compared to the inside cladding temperature of 340°-400°C while the fuel is in the reactor.[48]

Corrosion resistance of fuel cladding -

The metal cladding surrounding the fuel pellets is an important containment barrier that helps to keep the fission products within the fuel separated from the biosphere. The experience with spent fuel stored for periods up to twenty years shows no evidence of corrosion either on the outside or the inside of the cladding. This should be expected since the cladding has been designed to endure several years of the much more corrosive conditions of reactor operation where one year of reactor exposure is equivalent to many years of pool storage exposure. General corrosion rates under water basin storage conditions are very low. The amount of corrosion extrapolated to 100 years is 0.3 to 0.5 microns (0.05 to 0.07% of the cladding thickness) for Zircaloy and less than 1.5 microns (less than 1%) for stainless steel.[49] Other degradation mechanisms such as hydriding, fission product attack, helium embrittlement, oxidation, radiation, stress corrosion and cracking, galvanic effects and pitting corrosion, have been examined.[50] Assessments by four different investigators have identified no mechanisms that can be regarded as a substantial threat to fuel cladding integrity.[51] Based upon the studies of several independent evaluators, storage of spent fuel in water for many decades is practicable.[52, 53]

The results of these studies have been in general agreement as shown by the following excerpts.

> "The favorable storage experience, demonstrated technology, successful handling of fuel with reactor induced defects, benign storage environments, and corrosion-resistant materials offer sufficient bases to proceed with expanded storage capacities and extended fuel storage until questions regarding fuel reprocessing and final storage of nuclear wastes have been resolved. Some surveillance is justified to detect degradation if it becomes significant. Surveillance programs are already underway in several countries."[54]

> "Degradation mechanisms such as general corrosion, local corrosion, stress corrosion, hydrogen embrittlement, and delayed hydrogen cracking are not expected to produce degradation to any significant extent for 50 years. The risk of continued degradation of fuel that was defective when put into storage is shown to be small. The manageability of high burnup fuel is good and there is extensive experience and well developed routines for such handling . . ."[55]

<u>Leaching resistance of irradiated UO_2 pellets</u> -

The uranium oxide ceramic fuel pellets, themselves, provide a remarkably efficient barrier to the leaching of radioactive material into basin water. The pellets are virtually inert to pool water and there has been no observable degradation in several years of exposure of bare pellets to basin water. This property enhances the containment of the fission products by minimizing the impact of a potential defect in the fuel cladding.[56]

Encapsulation -

Encapsulation has been considered as a means of isolating defective or failed fuel in basin storage. The impact of fuel rod failures during storage, however, has been found to be relatively slight.[57] Release of leachable radioactive material to the basin water is strongly constrained by the limited exposure of the sintered ceramic UO_2 surface and by the extreme insolubility of the UO_2. Thus, encapsulation has not been deemed necessary at most fuel storage facilities. However, encapsulation is routinely used in Canada for the storage of defective fuel (because of the particular refueling technique used) and is occasionally used in U.S. storage facilities.[58] Dry storage techniques use encapsulation in order to prevent or retard the release of radioactive materials to the gaseous cooling system.[59] Thus, encapsulation techniques are available and can be used in the event that degradation of the fuel assemblies should occur. And if degradation of an encapsulation canister should occur after extended pool storage, there appears to be no reason why the fuel could not be removed from its original canister and placed in a new one.

Spent fuel storage study programs -

A broad-based surveillance program involving several countries is studying the nature of spent fuel in extended storage.[60-64] A variety of examination methods are being used or proposed for the program including neutron radiography, metallographic examinations and corrosion (coupon) studies[65]. Because of the ready accessibility of spent fuel while in water basin storage, visual monitoring (including monitoring for escaping gas bubbles) and radiation monitoring of the pool water (including "sipping") can detect major fuel degradation. Many opportunities for visual observation of the fuel are provided during relocation in the pool, fuel shuffling or during fuel shipments. Radiation levels of the pool water typically are monitored frequently. Concentrations of airborne radioactive materials above the pool are monitored continuously.[66]

In addition to the detailed examination of selected fuel bundles described in Section III.D above, surveillance studies are underway in the U. S., Canada, Germany, Belgium, Sweden and the United Kingdom.[67] Johnson states, "The favorable performance of spent fuel in storage and the benign storage conditions suggest that any surveillance program should be scoped to reflect the favorable storage experience".[68] The backup surveillance program will aid in early identification of corrosion trends. If any changes are seen there will be ample time to determine the appropriate fixes and to implement them.

D. Spent Fuel Pool Structures

In addition to the protection afforded by the fuel rod cladding and the sintered ceramic fuel pellets, protection is also afforded by the integrated system components, including the basin water, basin structure, building structure, ventilation system and radioactive waste treatment system. None of these involve unique, complicated or exotic techniques. Rather, they are based on standard design techniques, engineering design conservatism, existing chemical properties and normal construction practices.

The pool liners and equipment themselves have produced very little evidence of corrosion. As noted above, U. S. spent fuel pools are typically lined with stainless steel. Pool water is demineralized (in the case of PWR's, with boric acid added). PWR pools are slightly acidic (pH of 5-6) and BWR pools are neutral (pH of 7). Typical design temperatures are 120°-125°F (49°-52°C) for normal operations and 150°F (66°C) for abnormal operations. At these conditions, corrosion rates for spent fuel pool materials are low.[69] A corrosion study conducted at the Morris Operation pool indicated rates of corrosion on stainless steel in pool water to be extremely small. While some concern has been expressed with respect to corrosion of aluminum, the corrosion rates (even extrapolated to 100 years) would not constitute a threat to mechanical integrity. Aluminum has functioned satisfactorily in canisters and racks in some pools for approximately 17 years.[70]

In the event that corrosion or degradation of the pool liner, piping or equipment did occur, it could be remedied by repair or replacement. Pipes and pumps can be easily replaced if needed. Even where the pool liner is damaged, it can be repaired in place and in fact such repairs have been performed.[71]

The pool structure as well as the racks are designed to withstand the extreme physical conditions set forth in NRC licensing requirements. These include seismic, hydrologic, meteorological and structural requirements.[72] Compliance with these requirements provides a high degree of assurance that the pool will withstand conditions far more severe than are likely to occur. The 3/16 to 1/4 inch thick stainless steel liner, in addition to a pool structure of several feet of reinforced concrete,[73] itself provides substantial protection.

E. Siting Considerations

The vast majority of all spent fuel is stored in reactor spent fuel pools. Thus, the siting considerations for these pools are those of the reactor itself. These siting considerations are reviewed by the NRC Staff, the Advisory Committee on Reactor Safeguards, and the Atomic Safety and Licensing Board at the construction permit stage and then reviewed again in connection with issuance of the facility's operating license. Illustrative of the level of risk, analyses for the Barnwell storage pool indicate that the probability of damage to the pool from an earthquake is 6.5 x 10^{-7} per year (with the probability of catastrophic pool failure even smaller) and the probability of a tornado removing appreciable water from the pool is 5 x 10^{-7} per year.[74] These considerations provide high confidence that the design basis siting conditions will not be exceeded over long periods of time.

F. Systems Experience

In general terms, the thirty-seven years of experience with spent fuel storage has been excellent. As noted above,- individual fuel bundles have been stored in spent fuel pools for twenty years without adverse effects. Individual spent fuel pools have been in continuous operation for even longer periods. No safety or environmental problems have been detected during this period.

Fuel handling safety

The few cases of damage to fuel at reactor sites have occurred as a result of fuel handling mishaps. Only nine fuel handling accidents at reactor sites were reported in a recent three year period. These cases involved instances of core loading, refueling, and movements between the reactor and the spent fuel pool. Most of these did not involve the spent fuel pool. Only two of these accidents involved breaches in the cladding, even though the fuel assemblies may have dropped several feet through pool water before impacting.[75] Since longer term spent fuel storage would not involve significant additional movements of the fuel, the chances for fuel handling mishaps are reduced. In the eight years that the Morris Operation has been receiving spent fuel, 443 PWR assemblies and 761 BWR assemblies have been received and stored without damage.[76] Accidents involving the dropping of a cask are part of the design basis for the spent fuel pool, and steps are required to be taken to design against such accident or to enable the pool to withstand the event.[77]

Cooling system safety

Safe operation of spent fuel pools assumes that an adequate water level will be maintained in the pool and that backup water supplies are available. Fuel pool cooling systems are installed in each pool to maintain water temperature within design limits.[78] Typically, a reactor pool has two interconnected cooling systems, either one of which can remove normal heat generation.[79] Even if there should be a failure of all cooling, it would take many hours for the pool to reach boiling conditions and several days for enough water to boil off to possibly expose the spent fuel.* During this period of time, many water sources would be available to assure the existence of adequate water.[81]

Loss of cooling for a facility holding "older" fuel is even less significant because of the lower heat generated. In fact, at the Morris Operation, the pool was operated for several weeks without the cooling system in operation. The equilibrium temperature that was reached was 46°C.[82] Calculations for the West Valley pool and other AFR pool designs show that the time-to-boiling under worst-case conditions is 33 to 48 hours.[83] The actual heat load is substantially less than the maximum predicted because of conservatisms in calculations and operational constraints on the rates at which fuel can be added to the basin. With the conservative design characteristics and the long periods of time available to take remedial action, total loss of water is not a credible possibility.[84]

<u>Water clean-up safety</u>

High purity water in the storage pool provides protection for the containment barriers, i.e., fuel cladding and the basin liner. Basic chemistry control generally does not present operational problems.[85] Water purification systems are used to remove both particulate matter (which could affect visibility of the fuel through the pool water) and chemical and radiochemical materials which might have the potential for corrosion. These systems have functioned successfully. For example, the average total cesium concentration in the pool water at Morris Operation is 3×10^{-4} microcuries per milliliter,[86] a level that barely qualifies it as a controlled material as defined in 10 CFR Part 20. Even when water purification systems become unavailable, the increase in the contaminant level is slow as a result of the large amounts of water and the small amounts of impurities.[87]

Environmental radiological effects

Radiological effluents from spent fuel storage facilities are small and decrease with the length of storage. The driving forces for the transfer of radioactivity to the pool water from spent fuel are small.[88] The older the spent fuel, the smaller the driving forces and therefore the smaller the amount of radioactive material transferred to the pool. Most radioactive material in the pool water comes from deposits on the outside of the fuel assemblies which are accumulated while the fuel is in the reactor and are dislodged during fuel handling. Extended storage would not increase this source.[89] The release of fission products (principally from the deposits on the outside of fuel assemblies) occurs primarily immediately after fuel is removed from the core.[90]

Population exposures are extremely small from spent fuel pool operations. For example, the expansion of the Cook spent fuel pool has been estimated to result in additional total body doses to an individual and the 50 mile population of less than 0.001 mrem/year and 0.01 man-rem/year, respectively.[91] While most of this dose is calculated on the assumption that there is leakage of krypton-85 from fuel elements, actual krypton leakage from "aged" fuel is in fact too low to measure.[92]

Non-radiological environmental impacts

Long-term storage of spent fuel would cause insignificant non-radiological environmental effects. As discussed above, heat generation of spent fuel falls off sharply with age. The maximum rate of additional heat emitted by a plant as a result of increasing the number of spent fuel assemblies stored would generally be less than one percent[93] and has been calculated for one facility to be 0.05%.[94] Land use would also be insignificant, about 600 acres for a new AFR.[95] In most, if not all, cases an at-reactor spent fuel storage facility could easily be located on the existing reactor site.

Occupational radiological experience

Storing spent fuel in reactor pools, at reactor basins, or in AFR's will not significantly increase occupational radiation exposures. Pool operations generally involve low levels of occupational exposure, much of which is attributable to refueling activities. For example, at the Prairie Island facility, these activities resulted in occupational exposures of 2.3 to 4.5 man-rem/year.[96] Because most radiation exposure results from the more recently discharged fuel, allowing "older" fuel to remain in the pool will not significantly increase occupational exposures. For example, reracking of the Cook facility was estimated to increase occupational exposure by not more than one percent.[97] NRC calculates occupational exposures from spent fuel storage to average 0.02 man-rem per metric ton.[98] Occupational exposures for the life of the Barnwell facility have been calculated on a variety of assumptions for storage capacities of 360 to 5000 MT; these values range from 220 to 608 man-rem dose commitment.[99]

Dry storage

As discussed above, various concepts for dry storage of spent fuel have been investigated and a limited amount of spent fuel is currently being stored in that condition. Long-term corrosion of Zircaloy-clad spent fuel stored in air is very low at the relatively low storage temperatures envisioned. Additional studies are necessary to determine what degree of temperature control is required for long-term storage in air.[100] Storage of spent fuel in helium-filled canisters, now being tested by DOE, would alleviate this possible concern.[101]

VII. Ability to Increase Present Capacity and Cost

A. Expansion of reactor pool capacity

As discussed above, reracking of reactor spent fuel pools has been the method used most frequently by utilities to provide for increased storage capacity, and therefore longer term storage, of spent fuel. The ability to expand capacity of existing reactor pools is based on plant-specific design considerations, including pool size and configuration, structural design, seismic conditions and pool cooling capacity. Although some reactor spent fuel pools are projected to reach their maximum estimated capacity by the early 1980's, most can be increased in capacity to provide adequate capacity through the late 1990's and into the first decade of the next century.[102] The physical process of reracking an existing spent fuel pool can be accomplished in a matter of several months[103] and has been done with spent fuel already stored in the pool. Fabrication of spent fuel storage racks is not considered to be a lengthy process.*

Licensing the expansion of existing spent fuel pools has to date been accomplished without delaying the needed in-service date for the increased storage. NRC has reviewed and approved over forty applications to increase spent fuel pool storage capacity. These have included reracking based on closer spacing, poisoned racks, more racks, and combinations of these. The licensing involves no unusual or difficult safety issues. Basic siting questions, of course, have been previously resolved in connection with the licensing of the reactor. Contested proceedings have delayed approvals in some cases, but even in these proceedings, the added time has not yet caused interference with plant operations.** NRC has completed its Generic Environmental Impact Statement on spent fuel storage and has issued environmental impact appraisals for each rerack application.

---

* For example, fabrication of poisoned racks to replace the present racks in the Prairie Island Nuclear Generating Plant's spent fuel pools is estimated to take 15 months.[104]

** For example, in the contested NRC proceeding to expand the Prairie Island spent fuel pools, approval by the Atomic Safety and Licensing Board came 9 months after the application was filed with NRC. In the contested Zion proceeding, ASLB approval came 22 months after the license amendment application was filed. NUREG-0575 provides an estimate of 18 months from issuance of the contract to installation of racks.[105]

Expanding the capacities of existing spent fuel pools does not appear to involve difficult questions of public acceptability. The Presidential policy statement on waste management of February 12, 1980, calls for utilities to provide adequate spent fuel storage.[106] The report of the Interagency Review Group on Nuclear Waste Management stated that to "the maximum extent possible spent fuel should be stored at reactors".[107] Nationally based interest groups such as Natural Resources Defense Council and Union of Concerned Scientists have argued in favor of requiring maximum compaction in existing at-reactor pools.[108]

The costs of reracking existing pools are quite low. Typical costs are presented in the NRC's GEIS and range from $1 million to $5.5 million, depending on the stage at which the modification occurs and the type and size of the reactor.[109] The cost per additional metric ton of uranium is $3,400 to $18,000 (0.014 to 0.075 mills per kilowatt hour.)* Recent DOE estimates show a capital cost of $2.8 million for a 400 MTU pool, or $7,000 per MTU (0.029 mills/kwh).[110] Other estimates reported by DOE range from $4,800/MTU to $7,200/MTU (0.02 to 0.03 mills/kwh).[111] These values are consistent with information on individual projects.* Reracking costs are thus an

* The conversion from dollars per MTU to mills per kilowatt hour is based on burnup rate of 30,000 MWD/MTU, a 32% plant thermal efficiency, and a 30 MT/year discharge rate.

insignificant additional cost both in absolute terms and in comparison to the value of the energy generated.

B. At-reactor independent spent fuel pools

Building an independent spent fuel pool at an existing reactor site is another option for increasing spent fuel storage capacity and thus providing the space for longer term spent fuel storage. Although such a facility has not yet been constructed, there are neither significant technical, economic nor institutional barriers to such plans. TVA has proposed a spent fuel program based on at-reactor pools.[113]

From a technical standpoint, an at-reactor pool is relatively straightforward. Since it would be located at the site of an already licensed reactor, the siting criteria for reactors would already have been applied to the at-reactor site. The design of the facility would also be straightforward and similar to that of existing spent fuel pools. The design for the proposed TVA at-reactor pools has been characterized

> "as a large, steel-reinforced concrete structure with walls several feet thick having a 30- to 40-foot deep stainless steel lined pool in its middle. Supported on bedrock, the storage pool is designed to retain its watertight integrity for all design accidents, including tornadoes and earthquakes".[114]

---

* For example, the proposed reracking of the Donald C. Cook spent fuel pool is estimated to cost $4.7 million, or about $6,730 per additional metric ton uranium.[112] (Assuming each PWR assembly represents 0.45 MTU.)

Typical licensing requirements are set forth in NUREG-0575, App. B.[115] The Commission's proposed 10 CFR Part 72, "Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)", would govern if the at-reactor facility were a self-contained installation not "coupled" to the nuclear power plant. The alternative of at-reactor storage has already been generically examined from an environmental standpoint in NUREG-0575 and in the generic environmental impact statements issued by DOE on U.S. spent fuel policy[116] and the environmental impacts determined to be minor.

Because an at-reactor pool would involve design and construction of a new facility, the time for implementation would be significantly greater than for reracking. TVA has estimated the total lead time to be 7 years.[117] NRC estimates a total implementation time of 4 to 6 years.[118] DOE estimates an implementation time of 6-1/2 years.[119]

Cost estimates for at reactor spent fuel pools of course depend on the size. The following table presents a range of cost estimates for different size facilities.

TABLE 4. Cost Estimates for At-Reactor-Site Facilities

AFR Capacity (MTU)	Capital Cost (million $)	Cost in $/MTU	Cost in mills/kwh	Reference
900	$ 28	$31,000	0.13	TVA[120]
1000	$ 20-30	$20,000-30,000	0.08-0.13	NRC[121]
1200	$ 41	$34,000	0.14	TVA[120]
1400	$ 24.4	$17,000	0.07	NRC[121]
1900	$ 66	$35,000	0.15	DOE[122]
2000	$ 30-40	$15,000-20,000	0.06-0.08	NRC[121]
2400	$ 52	$22,000	0.09	TVA[120]

While these cost estimates vary with the different assumptions used by the estimators, all fall within a reasonable range. None of these costs is prohibitively expensive in terms of overall nuclear power generation economics for which a typical total cost is 20 mills/kwh.

Because an at-reactor spent fuel storage facility would be constructed at an existing reactor site, public acceptability should not be a significant hurdle. As noted above, some interest groups would require the maximum at-reactor storage.[123] As a part of its spent fuel management program study, TVA undertook a wide-ranging process of public participation, including a series of public forums, review by six independent consultants (including an NRDC staff scientist), and requests for public comments (a majority of which approved of the on-site storage concept).[124]

C. Away-from-reactor spent fuel pools

The third alternative is storage at existing, expanded or new spent fuel storage facilities at away-from-reactor sites (AFR's). As noted above, three such pools already exist (Morris, West Valley and Barnwell), with the first two already licensed and storing spent fuel.

Siting and design of a new AFR would be governed by the principles set forth in proposed 10 CFR Part 72, which include a set of General Design Criteria comparable to those set forth in 10 CFR Part 50 for reactors[125] as well as a set of siting criteria.[126] According to the NRC Staff, it is planned that the final version of these regulations will be issued within the next several months. Licensing under proposed Part 72 would occur at the pre-construction stage. The time needed to place an AFR at a new site into operation has been estimated at 9-1/2 years by TVA,[127] 8 years by DOE,[128] and 4 to 6 years by NRC[129] (note that the shorter period appear to apply to storage facilities at existing sites).

Licensing of a new AFR would be facilitated by the existence of regulations specifically governing its siting and design. Also, NRC and DOE have concluded their generic NEPA reviews of the spent fuel storage program, including AFR's.

Based on current Administration policy, a new AFR will most likely be a Federal project. Existing AFR's could be acquired by the Federal government to provide storage capacity in the short to mid term. Legislation has been introduced in Congress to authorize various aspects of the federal AFR program.[130-132] These bills call for various combinations of studies, construction authorization and financing authorization. Although these pieces of legislation are still pending, studies called for by some of the proposals have already been transmitted to Congress.[133] Legislation to appropriate funds for the program has been enacted.[134] The availability of Federal AFR capacity has been called for by the Interagency Review Group,[135] the President,[136] NRC[137] and DOE.[138] These factors make the eventual establishment of Federal AFR facilities quite likely. The need for AFR's has also been recognized by at least one joint environmentalist/industry/ academic group, the Keystone Discussion Group on Radioactive Waste Management,[139] and by the National Association of Regulatory Utility Commissioners.[140]

Since the AFR facilities most likely to be available in the near term are those already in existence, the potential public acceptability problems associated with siting a new facility will be mitigated. For example, the Governor of South

---

* The Oak Ridge, Tennessee, city commission has petitioned TVA to build an AFR in Oak Ridge.

Carolina has indicated the acceptability of the Barnwell facility as a regional AFR in the context of a comprehensive waste management plan.[141] Even as to new sites, at least one location has actively sought the siting of an AFR in its jurisdiction.* The inclusion of interim spent fuel management in the charter of the State Planning Council on Radioactive Waste Management[142] by assuring an important State and local role in AFR decisions will help to achieve public acceptability. Completion of the NEPA process for site specific decisions and NRC licensing of such facilities will provide further opportunities for public input.

The time needed for AFR capacity depends on the nature of the project. A new AFR could take 8 years from the start of final design to initial fuel receiving.[143] However, AFR storage facilities could be available by late 1983 through acquisition of existing facilities, if pending legislation is enacted and NEPA requirements are met.[144] With reracking of existing AFR's, no new AFR's would be needed for at least a decade.

Although the costs of constructing an AFR are considerably larger than the cost of reracking, they are still a small fraction of total fuel cycle costs. DOE has collected the cost estimates prepared by other organizations for a new AFR. These

---

* The Oak Ridge, Tennessee, city commission has petitioned TVA to build an AFR in Oak Ridge.

estimates range from $175 to $350 million for a 5000 MTU facility ($35,000 to $70,000 per MTU or 0.15 to 0.29 mills/kwh) and $90 to $250 million for a 3000 MTU facility ($30,000 to $83,000 per MTU or 0.13 to 0.35 mills/kwh).[145] The DOE estimates are $250 million for a 5000 MTU AFR ($50,000 per MTU or 0.21 mills/kwh) and $350 million for an expanded AFR with a 10,000 MTU capacity ($35,000 per MTU or 0.15 mills/kwh).[146] TVA's most recent estimates are $111 million for a 2400 MT facility ($46,250 per MTU or 0.19 mills/kwh) and $308 million for a 9000 MTU facility ($34,200 per MTU or 0.14 mills/kwh).[147]

VIII. Availability of Transportation for Spent Fuel Storage Facilities to Permanent Repositories

Spent fuel will have to be shipped from reactors either to interim storage facilities and then to permanent repositories or directly to permanent repositories. This will require the availability of adequate numbers of spent fuel shipping casks.

Up to the present time, there have been relatively few spent fuel shipments. In 1979, for example, there were approximately 50 shipments of commercial spent fuel in the U. S., handled by the existing U. S. fleet of thirteen truck casks and six rail casks.[148] Additional truck and rail casks will be required as shipments of spent fuel increase with the operation of AFR's and permanent repositories.

The number of casks and their timing depends on the particular strategies chosen, including the need to ship spent fuel to AFR's, the timing and loading/unloading capability of AFR's and the timing and loading capability of permanent repositories. Many studies are in progress to develop these strategies.[149] Present cask availability is, however, likely to be adequate at least until the mid 1990's. The present cask fleet has an annual transportation capacity of about 1500 metric tons.[150] As shown in Section IV above, annual AFR requirements (which would equal shipments to AFR's) do not reach 1500 metric tons until 1993.

The design and licensing of new casks is not likely to be a limiting factor, particularly since much of the fuel to be moved will be stored at the reactor site for at least five years. Six different cask designs for commercial spent fuel shipment are already in current use.[151] Once the initial license application for a design is approved, little additional licensing is involved.[152] A new design might take from one to three years, with another year for licensing.[153] However, use of the existing, previously licensing designs avoids the need for this delay.

Fabrication of additional casks will be a function of demand. Because of the massive nature of the casks, relatively few manufacturers currently have the capability to fabricate them.[154] Even with this manufacturing limitation, NRC estimates that cask fabrication times are relatively short, from 10 months to 3 years to fabricate a truck cask and one and a half to four years for a rail cask.[155] Cask vendors estimate average fabrication times of 1.5 years for truck casks (with a range of 1 to 2 years) and 2 years for a rail cask (with a range of 1 to 3 years).[156] There is sufficient U. S. manufacturing capacity to fabricate three to six casks per year.[157] Additional future demands would encourage cask vendors to develop additional fabrication capability. With the relatively short lead times and the relatively long period before additional casks are needed, cask availability is unlikely to be a limiting factor.

REFERENCES

1. U. S. Nuclear Regulatory Commission, Final Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575, August 1979, p. ES-3.

2. For example, see Commonwealth Edison Company, Special Report No. 43, Dresden Station, Fuel Storage Pool Modification (Docket Nos. 50-237, 50-249) (December 8, 1975).

3. For example, see U. S. Nuclear Regulatory Commission, Environmental Impact Appraisal by the Office of Nuclear Reactor Regulation Supporting Amendment No. 19 to Facility Operating License No. NPF-3, Davis-Besse Nuclear Power Station, Unit No. 1 (August 1, 1979).

4. Op. cit., U.S.N.R.C. (Ref. 1), p. 3-5.

5. U. S. Nuclear Regulatory Commission, Environmental Impact Appraisal by the Office of Nuclear Reactor Regulation Relating to the Modification of the Spent Fuel Storage Pool, Donald C. Cook Nuclear Plant (October 16, 1979).

6. Op. cit., U.S.N.R.C. (Ref. 1), p. 3-5.

7. Johnson, A. B. Jr., "Utility Spent Fuel Storage Experience", PNL-SA-6863, presented at American Nuclear Society- Executive Conference on Spent Fuel Policy, Buford, Georgia (April 2-5, 1978).

8. Op. cit., U.S.N.R.C. (Ref. 1), p. ES-3.

9. Johnson, A. B. Jr., Behavior of Spent Nuclear Fuel in Water Pool Storage, BNWL-2256 (UC-70), Battelle Pacific Northwest Laboratories, September 1977, p. 6.

10. U. S. Department of Energy, Study on Spent Nuclear Fuel Storage, DOE/SR-0004 (March 1980), vol. 1, p. 5.

11. Letter from D. M. Dawson, General Electric Co., to L. C. Rouse, NRC, Docket No. 70-1038 (May 1, 19[illegible]) and attached Table "Fuel Storage--Existing Morris Operation Space".

12. Op. cit., U.S.D.O.E. (Ref. 10), vol. [illegible] 8.

13. Op. cit., Johnson (Ref. 9).

14. Op. cit., Johnson (Ref. 7).

15. Mayman, S. A., Canadian Experience with Wet and Dry Storage Concepts, Presented at American Nuclear Society-Executive Conference Spent Fuel Policy and Its Implications, Buford, Georgia (April 2-5, 1978).

16. Op. cit., Johnson (Ref. 7).

17. Op. cit., Johnson (Ref. 6), p. 17.

18. Op. cit.

19. Op. cit., pp. 17, 19.

20. Op. cit., Johnson (Ref. 7), p. 7.

21. Op. cit., Johnson (Ref. 9), pp. 17-18.

22. Walker, J. F., The Long-Term Storage of Irradiated CANDU Fuel Under Water, AECL-6313 Whiteshell Nuclear Research Establishment, January 1979.

23. Hunt, C.E.L., J. C. Wood and A. S. ,ain, Long-Term Storage of Fuel in Water, AECL-6577, Chalk River Nuclear Laboratories, June 1979.

24. Johnson, A.B. Jr., "Spent Fuel Storage Experience", Nuclear Technology, (vol. 43, Mid-April 1979), 171.

25. Op. cit., U.S.D.O.E. (Ref. 10).

26. U. S. Department of Energy, Spent Fuel Storage Requirements--The Need for Away-From-Reactor Storage, DOE/NE-002 (an update of DOE/ET-0075) (January, 1980).

27. U. S. General Accounting Office, "Federal Facilities for Storing Spent Nuclear Fuel--Are They Needed", EMD-79-82 (June 27, 1979).

28. Rotow, "NRDC Findings on the Alleged Need for Acquisitior or Construction of an Away-From-Reactor Spent Fuel Storage Facility" (Natural Resources Defense Council, March 26, 1979).

29. Tennessee Valley Authority, Spent Fuel Management Program Study Summary Option Paper, May, 1979.

30. Tennessee Valley Authority, Spent Fuel Management Program Study Summary Report, September, 1979.

31. Op. cit., pp. 8-9.

32. Op. cit., U.S.D.O.E. (Ref. 10).

33. Op. cit., U.S.N.R.C. (Ref. 1).

34. Environmental Impact Appraisal By The Office of Nuclear Reactor Regulation Supporting Amendment to DPR-45,

Dairyland Power Cooperative, LaCrosse Boiling Water Reactor (July 13, 1979).

35. Op. cit., T.V.A. (Ref. 30), pp. 9-10.

36. U. S. Department of Energy, Final Environmental Impact Statement: U. S. Spent Fuel Policy, DOE/EIS-0015 (May, 1980), vol. 2, p. II-12.

37. Op. cit., Mayman (Ref. 15), p. 3.

38. U. S. Nuclear Regulatory Commission, Dry Storage of Spent Nuclear Fuel, NUREG/CR-1223 (April 1980).

39. Op. cit.

40. Westinghouse Electric Corporation, The Spent Fuel Handling and Packaging Program Demonstration at the Nevada Test Site (February 1980) (draft).

41. Op. cit., U.S.N.R.C. (Ref. 1) vol. 1, pp. 6-7.

42. Op. Cit., Johnson (Ref. 24), p. 167.

43. Op. cit.

44. Op. cit., Johnson (Ref. 9), p. 32.

45. Op. cit., U.S.N.R.C. (Ref. 1), vol. 1, p. 4-22.

46. Op. cit., Johnson (Ref. 7), p. 14.

47. Op. cit., U.S.N.R.C. (Ref. 1), vol. 1, p. 2-2.

48. Op. cit., Johnson (Ref. 24), p. 167.

49. Op. cit., Johnson (Ref. 7), p. 12.

50. Op. cit., Johnson (Ref. 9), pp. 55-72.

51. Op. cit., Johnson (Ref. 24), p. 171.

52. Op. cit., Johnson (Refs. 7, 9, 24), Walker (Ref. 22), Hunt (Ref. 23).

53. Vesterlund, G. and T. Olsson, Degradation Mechanisms During Pool Storage and Handling of Spent Power Reactor Fuel, ASEA - ATOM Preprint RB 78.29, January 18, 1978.

54. Op. cit., Johnson (Ref. 24).

55. *Op. cit.*, Vesterlund (Ref. 53).

56. *Op. cit.*, Johnson (Ref. 24).

57. *Op. cit.*, Johnson (Ref. 9), p. 18.

58. *Op. cit.*, Johnson (Ref. 24), p. 170.

59. *Op. cit.*, Mayman (Ref. 15); Westinghouse Electric (Ref. 40); U.S.N.R.C. (Ref. 38), p. I-6.

60. *Op. cit.*, Hunt (Ref. 23); Mayman (Ref. 15).

61. Warner, B. F., *The Storage in Water of Irradiated Oxide Fuel Elements*, Testimony presented at Windscale Inquiry on Spent Fuel Reprocessing, Windscale, U.K. September 1977.

62. Flowers, R. H., *Results of an Examination of Irradiated Oxide Fuel Following Storage in Water*, Testimony presented at Windscale Inquiry on Spent Fuel Reprocessing, Windscale, U.K., October 1977.

63. Huppert, K. L., *Spent Fuel Storage - Philosophies and Experience*, Proc. NEA Sem. Storage of Spent Fuel Elements, Madrid, Spain, June 20-23, 1978.

64. Peehs, M. et al, *Behavior of Spent LWR Fuel Assemblies*, Proc. NEA Sem. Storage of Spent Fuel Elements, Madrid, Spain, June 20-23, 1978.

65. *Op. cit.*, Hunt (Ref. 23), Johnson (Ref. 42).

66. *Op. cit.*, Johnson (Ref. 24), p. 169.

67. *Op. cit.*, Hunt (Ref. 23).

68. *Op. cit.*, Johnson (Ref. 24), p. 172.

69. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. II, p. B-2.

70. *Op. cit.*, Johnson (Ref. 9), pp. 72-74.

71. *Op. cit.*, p. 27.

72. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. II, App. B.

73. *Op. cit.*, vol. I, pp. 5-4, 5-6.

74. Darr, D. G., *Studies and Research Concerning BNFP--Safety and Environmental Impact of Interim AFR Storage In the BNFP-FRSS-Final Report*, AGNS-1040-1.5-63, Rev. 1 (March, 1979), p. A-6.

75. Op. cit., Johnson (Ref. 9), pp. 25-27, Johnson (Ref. 24), p. 171.

76. General Electric Co., Operating Experience-Irradiated Fuel Storage-Morris Operation, NEDO-20969 B2 (January 1979).

77. Op. cit., U.S.N.R.C. (Ref. 1), vol. II, pp. B-6-7.

78. Op. cit., p. B-15.

79. Op. cit.

80. Commonwealth Edison Co. (Zion Station, Units 1 and 2), Initial Decision, LBP-80-7, 11 NRC 245, 265-267 (February 14, 1980).

81. Op. cit., 11 NRC at 287.

82. Op. cit., U.S.N.R.C. (Ref. 1) vol. I, pp. 4-21,22.

83. Op. cit.

84. Op. cit., Commonwealth Edison (Ref. 80), 11 NRC at 266-268.

85. Op. cit., Johnson (Ref. 9), p. 35.

86. Op. cit., General Electric Co. (Ref. 76), pp. 3-5, 3-7.

87. Voiland, E. E., Experience in Operation of the Morris Operation Storage Facility, presented at the American Nuclear Society Executive Conference on Spent Fuel Policy and its Implications, Buford, Georgia, April 2-5, 1978.

88. Op. cit.

89. Northern States Power Co. (Prairie Island Nuclear Generating Plant, Units 1 and 2), Initial Decision, LBP-77-51, 6 NRC 265, 276 (1977).

90. Op. cit., at 278.

91. Op. cit., U.S.N.R.C. (Ref. 5), p. 21.

92. Op. cit., U.S.N.R.C. (Ref. 1), vol. I, p. 4-10.

93. Op. cit., p. 4-1.

94. Op. cit., U.S.N.R.C. (Ref. 5), p. 11.

95. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. 1, p. 4-2.

96. Northern States Power Company, Certificate of Need Application to Increase Storage Capacity of the Spent Fuel Pool, submitted to the Minnesota Energy Agency (September, 1979), p. 89.

97. *Op. cit.*, U.S.N.R.C. (Ref. 5), p. 21.

98. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. I, Table 4.3.

99. *Op. cit.*, Darr (Ref. 74), Table 5-26.

100. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. II, pp. H-22-24.

101. *Op. cit.*, Westinghouse Electric Corp. (Ref. 40).

102. *Op. cit.*, U.S.D.O.E. (Ref. 10), vol. II, App. A.

103. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. I, p. 6-3.

104. *Op. cit.*, Northern States Power Co. (Ref. 96), p. 21.

105. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. I, p. 6-3.

106. Presidential Message to Congress, "Comprehensive Radioactive Waste Management Program" *Weekly Compilation of Presidential Documents*, vol. 16, no. 7 (February 12, 1980).

107. "Report to the President by the Interagency Review Group on Nuclear Waste Management", TID-29442 (March 1979), pp. 62, 101.

108. *Oversight Hearings on Nuclear Waste Management Before the Subcomm. on Energy and The Environment of the House Comm. on Interior and Insular Affairs*, 96th Cong., 1st Sess. 99-103, 483-491 (1979) (statement by Natural Resources Defense Council) and 247, 265 (statement by Union of Concerned Scientists).

109. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. I, Table 6.1.

110. *Op. cit.*, U.S.D.O.E. (Ref. 10), vol. II, App. B, Table 4.

111. *Op. cit.*, p. B-2.

112. *Op. cit.*, U.S.N.R.C. (Ref. 5), p. 13.

113. *Op. cit.*, TVA (Refs. 29, 30).

114. Op. cit., TVA (Ref. 30), p. A-15.

115. Op. cit., U.S.N.R.C. (Ref. 1).

116. Op. cit., U.S.D.O.E. (Ref. 36).

117. Op. cit., TVA (Ref. 30), p. 4.

118. Op. cit., U.S.N.R.C. (Ref. 1), pp. 6-7, 8.

119. Op. cit., U.S.D.O.E. (Ref. 10), vol. I, p. 20.

120. Op. cit., TVA (Ref. 30), Table 2.

121. Op. cit., U.S.N.R.C. (Ref. 1), vol. I, p. 6-5.

122. Op. cit., U.S.D.O.E. (Ref. 10), vol. II, App. B., Table 4.

123. Op. cit., Oversight Hearings (Ref. 108).

124. Op. cit., TVA (Ref. 30).

125. Proposed 10 CFR Part 72, Subpart F, 43 Fed. Reg. 46309, 46319-20 (October 6, 1978).

126. Proposed 10 CFR Part 72, Subpart E, 43 Fed. Reg. 46309, 46318-19 (October 6, 1978).

127. Op. cit., TVA (Ref. 30), p. 4

128. Op. cit., U.S.D.O.E. (Ref. 10), vol. I, p. 6.

129. Op. cit., U.S.N.R.C. (Ref. 1), vol. I, p. 6-7.

130. "Spent Nuclear Fuel Act of 1979", H. R. 2586, 96th Cong., 1st Sess. (1979).

131. Department of Energy Authorization bill, H. R. 6627, 96th Cong., 2d Sess., §602 (1980).

132. "Nuclear Waste Policy Act", S. 2189, 96th Cong, 1st Sess., Title III (1979).

133. Letter from George W. Cunningham, Asst. Sec. for Nuclear Energy, DOE, to Hon. John D. Dingell, Chairman Subcomm. on Energy and Power, House Commerce Comm., dated March 31, 1980.

134. Public Law 96-69, Energy and Water Development Appropriation Act, 1980; Public Law 95-482, Appropriations for Fiscal Year 1979-Continuance.

135. Op. cit., IRG Report (Ref. 107).

136. President's Radioactive Waste Management Program, 16 Weekly Compilation of Presidential Documents, 296 (February 12, 1980 message to Congress).

137. Op. cit., U.S.N.R.C. (Ref. 1).

138. Op. cit., U.S.D.O.E. (Ref. 36).

139. Op. cit., Oversight Hearings (Ref. 108), p. 190.

140. Spent Fuel Storage and Disposal: Hearings before the Subcomm. on Energy and Power of the House Commerce Comm., 96th Cong., 1st Sess., Serial No. 96-97 (1980), p. 32.

141. Op. cit., p. 39.

142. Executive Order 12192 (February 12, 1980) §1-201, 45 Fed. Reg. 9727 (1980).

143. Op. cit., U.S.D.O.E. (Ref. 10), vol. I, Table 5

144. Testimony of Michael J. Lawrence, Director, Division of Transportation and Fuel Storage, U.S.D.O.E., before Minnesota Energy Agency, Docket EA-80-001-AK, (June 18, 1980).

145. Op. cit., U.S.D.O.E. (Ref. 10), vol. II, App. B, Table 3.

146. Op. cit., Table 4.

147. Op. cit., TVA (Ref. 30), p. A-6.

148. Op. cit., U.S.D.O.E. (Ref. 10), vol. I, p. 31.

149. See, for example, MITRE Corporation, Working Paper WP-80W00146, Radioactive Waste Disposal (February 19, 1980).

150. Op. cit., U.S.N.R.C. (Ref. 1), vol. I, p. 3-21.

151. Brobst, W. A., Another Institutional Issue--Standardization of Shipping Casks, presented at American Nuclear Society Executive Conference on Spent Fuel Policy and its Implications, Buford, Georgia, April 2-5, 1978.

152. Op. cit., U.S.N.R.C. (Ref. 1), vol. II, p. B-39.

153. *Op. cit.*

154. *Op. cit.*, U.S.N.R.C. (Ref. 1), vol. II, p. B-39.

155. *Op. cit.*

156. *Statement of Electric Utility Companies' Nuclear Transportation Group on Status and Future Availability of Spent Nuclear Fuel Casks and Shipping Services* (April 1979).

157. *Op. cit.*