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ABSTRACT

Wet storage has been the only licensed option for spent fuel management for U.S. commercial power reactor operators, except for a period of commercial reprocessing at the Nuclear Fuel Services facility, 1965-71. Developments are underway to bring dry storage to licensed status on the U.S. by mid-1986. However, wet storage will remain the predominant storage method, at least beyond the turn of the century.

The Nuclear Waste Policy Act of 1982 establishes current U.S. policy regarding responsibilities for spent fuel management.(1) The Nuclear Waste Confidence Rulemaking proceedings address the viability of extended wet storage for U.S. reactors.

U.S. utilities have moved aggressively to implement optimized utilization of wet storage technology, assisted in some areas by federal programs.

This paper summarizes U.S. policy and regulatory aspects of wet storage and the status of several wet storage technology developments, including:

* Dense Racking
* Double Tiering
* Credit for Burnup in Rack Designs
* Transshipment
* Impacts of Extended Burnup
* Rod Consolidation
* Pool Decommissioning

POLICY

In 1982 the U.S. Congress passed the Nuclear Waste Policy Act, which establishes the current U.S. policy for storage and disposal of spent nuclear fuel and nuclear waste.[1] The Act has the following provisions relating to interim storage of spent fuel:

Section 131:

* The persons owning and operating civilian nuclear power reactors have the primary responsibility for providing interim storage of spent nuclear fuel.

* The Federal Government has the responsibility to encourage and expedite the effective use of existing storage facilities and the addition of needed new storage capacity at the site of each civilian nuclear power reactor.

* The Federal Government has the responsibility to provide not more than 1,900 metric tons of capacity for interim storage of spent nuclear fuel for civilian nuclear power reactors that cannot reasonably provide adequate storage capacity at the sites of such reactors when needed to assure the continued, orderly operation of such reactors.

Section 218:

The Secretary (of Energy) also shall undertake a cooperative program with civilian nuclear power reactors to encourage the development of the technology for spent nuclear fuel rod consolidation in existing power reactor water storage basins.

The Act specifies that the federal government will begin to take title to commercial spent fuel in 1998.

REGULATION

The U.S. Nuclear Regulatory Commission is responsible for regulation of interim storage of commercial spent fuel, under the Federal Code of Regulations. Part 50 covers storage at power reactors. Part 72 covers storage at Independent Spent Fuel Storage Installations (ISFSI).

In 1979 the Nuclear Regulatory Commission initiated rulemaking proceedings to assess the degree of assurance that spent fuel and nuclear waste can be safely stored and disposed of. The U.S. Department of Energy had the lead responsibility to develop the technical bases to support the Commission decisions.(2) In a 1984 ruling, the Commissioners issued the following statement of confidence regarding wet storage:(3)

> "...if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the expiration of that reactor's operating license at that reactor's spent fuel storage basin, or at either onsite or offsite independent spent fuel storage installations."

WET STORAGE SCOPE AND SIGNIFICANCE

Figure 1 indicates the total U.S. commercial spent fuel discharges projected through 2000 AD, based on data in DOE/RL-85-2.(4) Also shown are the total projected capacities for U.S. wet storage facilities. It is clear that wet storage will remain the predominant interim storage method, even if all storage shortfalls at U.S. power reactors are met with dry storage technology. At-reactor pools are expected to remain in service as long as LWRs operate.

ROLES OF FEDERAL STORAGE PROGRAMS

Under the DOE Away-from-Reactor (AFR) Spent Fuel Storage Program, a data base was developed to demonstrate that LWR fuel can be safely stored in water for several decades.(2) That evidence and results from foreign programs

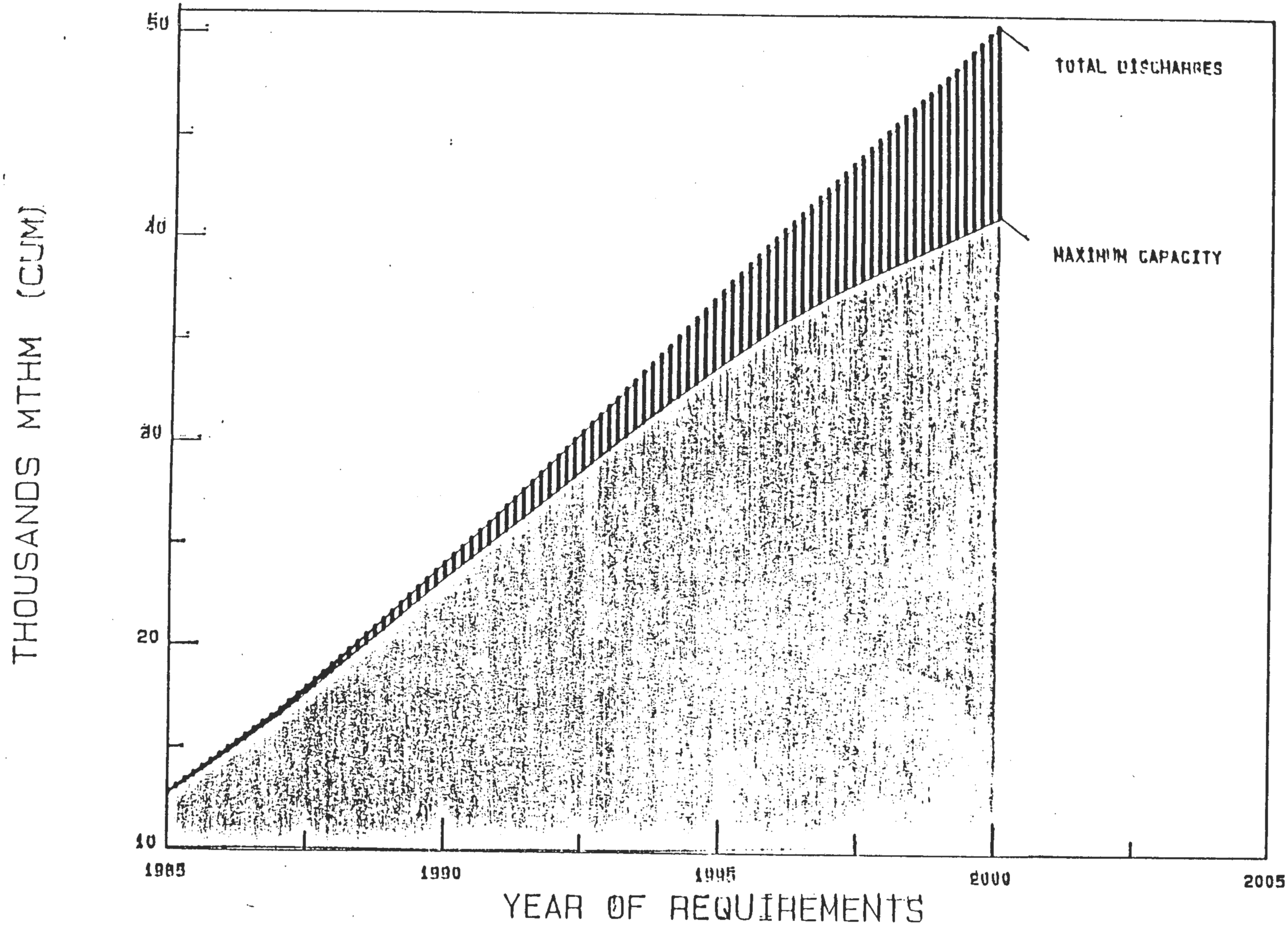

FIGURE 1. Additional Storage Requirements Compared to Total Spent Fuel Discharges(4)

provided the basis for a ruling of confidence for extended wet storage from the Nuclear Waste Confidence Rulemaking.[3]

Under the DOE-sponsored Commercial Spent Fuel Management (CSFM) program, generic research and development has focused on advancing the dry storage data base. However, generic studies related to wet storage have included: storage characteristics of fuel with cladding defects; crud behavior in extended wet storage; and technical aspects of rod consolidation.

Cooperative utility/DOE demonstration programs currently center on dry storage, but initiatives are underway to include an in-pool rod consolidation demonstration.

U.S. WET STORAGE TECHNOLOGY DEVELOPMENTS

DENSE RACKING

Most U.S. LWR power reactor pools have installed fuel storage racks that permit the minimum spacing between storage locations (see Table 1). Typically, reracking has expanded pool storage capacities from 4/3 to 11/3 reactor cores, using rack panels with neutron-absorbing materials (principally B_4C) between adjacent fuel assemblies.

TABLE 1. Storage Densities and Spent Fuel Assembly Center-to-Center Spacings for Various Rack Types in Spent Fuel Storage Pools[5]

Rack Type/Material	Storage Density, MgU^*/m^2 (MgU/ft^2)	Center-to-Center Spacing of Spent Fuel Assemblies, cm (in.)
Low-density/aluminum or stainless steel	0.023 (0.25)	Up to 33 (13) for BWR fuel and 56 (22) for PWR fuel
High-density (HD)/stainless steel	0.036 (0.39)	As low as 20 (8) for BWR fuel and 33 (13) for PWR fuel
Poisoned HD/stainless steel with added neutron absorber	0.054 (0.58)	16.5 (6.5) for BWR fuel and 26.7 (10.5) for PWR fuel
Double tier HD/stainless steel	0.072 (0.78)	--

*Megagrams (tonnes) of Uranium.

DOUBLE TIERING

Second tiers of racks may be installed if the pool is deep enough and the structure can cope with the added load.[6] Table 1 indicates that double tiering results in a substantial increase in storage density. Currently, two U.S. plants use double tiering: LaCrosse (BWR) and Yankee Rowe (PWR). The horizontal dimensions of the pool at LaCrosse are 11 ft (3.3 m) by 11 ft, and the racks are 18 ft (5.5 m) high. Using denser racks and double tiering increased the storage capacity to 440 fuel assemblies (original capacity, 133 assemblies). Fuel assemblies stored in the lower tier are always accessible (e.g., for periodic surveillance) when the corresponding upper tier location is vacant. At Yankee Rowe, use of double tiering increased the maximum storage capacity to 721 fuel assemblies (original capacity, 391 assemblies). The double tier racks are 20 ft (6.1 m) high. The total pool depth is 35 ft (10.7 m).

CREDIT FOR BURNUP

Several U.S. PWR pool operators have been licensed to take credit for fuel burnup in the design of storage racks. To date, requirements include:

installation of different rack designs in two regions of the pool to handle the potential range of fuel reactivities; strict administrative controls on fuel placement; verification of fuel burnups by independent calculations (note: use of burnup meters is under consideration). IAEA regulations allow for burnup credit in shipping casks.[7]

TRANSSHIPMENT

Transshipment involves shipment of spent fuel between two reactor pools, generally owned by a single utility, to relieve impacted storage at one of the reactors. Transshipment requires licensing by the Nuclear Regulatory Commission. Maximum use of transshipment in U.S. pools could reduce additional storage needs by approximately 1400 MTU by 2000 AD.[4] Shipping fuel to another site provides limited additional but temporary storage capacity, and licensing has been a difficult and time-consuming process.[8] To date, transshipment has been utilized on a limited basis in the U.S.A.

IMPACTS OF EXTENDED BURNUP

Increasing burnup trends for U.S. LWR fuel are expected to have a significant effect on spent fuel storage requirements. Table 2 summarizes the current estimate of the reduction in U.S. storage requirements if fuel burnups increase as expected.

TABLE 2. Effects of Extended Burnup on U.S. LWR Spent Fuel Storage Requirements

	Additional Storage Requirements U.S. Reactor Pools, MTU[a]		
	1990	1995	2000
Utility projected discharges	759	3392	9332
Extended burnup[b]	572	2236	4742

(a) Spent Fuel Storage Requirements, DOE/RL 85-2.[4]
(b) Assumes 3%/year increase in burnup up to maximum of 45 GWd/MTU for PWR and 38 GWd/MTU for BWR fuel.

ROD CONSOLIDATION

Rod consolidation is a leading candidate for more efficient utilization of existing space in spent fuel storage pools and also has the potential to be applied to dry storage of LWR fuel. Rod consolidation involves mechanically removing all fuel rods from the fuel assembly hardware and placing them either in another grid with closer spacing or in a close-packed array in a canister without a spacer grid. The status of rod consolidation in the U.S. is described in a recent paper[9] and report.[10] The experience base for consolidation of irradiated LWR fuel in the U.S. is shown in Table 3.[11] Disposal of nonfuel-bearing components from fuel assemblies is an important consideration in rod consolidation. One key engineering variable is the dose rate from certain isotopes (e.g., cobalt-60 and niobium-95) formed when impurities in those components (e.g., Inconel spacer grids) are irradiated.[12]

The ANS-57.10 Working Group was organized to develop the standard entitled "Design Criteria for Consolidation of LWR Spent Fuel" for the nuclear industry. A draft of the standard has been prepared that covers rod consolidation in wet or dry environments, with fuel assemblies and rods in vertical or horizontal attitudes. The latest version of the draft (May 1985) was submitted to the American Nuclear Society Nuclear Power Plant Standards Committee (NUPPSCO). The draft was reviewed by NUPPSCO at its meeting in October 1985. The draft will be revised at the next ANS-57.10 Working Group meeting in April 1986 and will then be resubmitted in about June 1986 to NUPPSCO for ballot.

Rod consolidation of irradiated fuel has been demonstrated on a limited scale in the United States. Compaction ratios up to 2:1 have been attained with irradiated fuel rods. However, further development is needed on consolidation systems to automate the processes and make them economical for large-scale use. There has been no experience with extended wet or dry storage of consolidated fuel rods, but problems are not expected.[8] Consolidated fuel rods (up to 2:1 consolidation ratio), in wet storage at the Oconee Nuclear Station since late 1982, represent the world's first storage experience for consolidated irradiated fuel.

TABLE 3. Experience Base for Consolidation of Irradiated LWR Fuel

	No. of Unirradiated Fuel Assemblies BWR	No. of Unirradiated Fuel Assemblies PWR	Consolidation Operation Medium	Comments
Cold Demonstrations				
• Allied General Nuclear Services	--	4	Dry	Done in horizontal position. A total of 17 runs were made with the 4 assemblies.
• Nuclear Assurance Corp.	--	6	Wet	
• U.S. Tool & Die, Inc.	1	--	Wet	
• Westinghouse Electric Corp.	--	3	Wet and Dry	There were multiple campaigns with the 3 assemblies.

Hot Demonstrations (Date)	Nuclear Station	No. of Irradiated Fuel Assemblies	Consolidation Ratio	Consolidation Operation Medium
• Westinghouse Electric Corp./Duke Power Co. (Oct.-Nov. 1982)	Oconee	4 PWR	2:1[(a)]	Wet
• Maine Yankee Atomic Power Co. (Aug. 1983)	Maine Yankee	1 PWR	1.6:1	Wet

Upcoming of Proposed Demonstrations	Reactor or Site	Fuel Assemblies No.	Fuel Assemblies Type	Probable Date	Consolidation Operation Medium	Comments
• Nuclear Assurance Corp.	Facilities at West Valley,[(b)] NY	11	PWR (Ginna)	Dec. 1985-early 1986	Wet	As of early February 1986, nearly 6 assemblies have been consolidated. Rods are pulled one at a time. The highest compaction ratio achieved so far is 1.8:1 in one canister.
• Nuclear Assurance Corp.	Browns Ferry	12	BWR (Browns Ferry)	Late 1986	Wet	Equipment installed in pool. Rod consolidation will not start until at least September 1986.
• U.S. Tool & Die, Inc.	Battelle Columbus Laboratories (BCL)	2	PWR (Ginna)	1986	Wet	Planned for Spring 1986.
• INEL[(c)] and Virginia Power Company	TAN[(d)]	80	PWR (Surry)	March 1987	Dry	
• Maine Yankee Atomic Power Company	Maine Yankee	20	PWR (Maine Yankee	?	Wet	Self-funded program that involves intact fuel.
• Combustion Engineering/EPRI, Northeast Utilities Service Co., and Baltimore Gas and Electric Co.	Millstone-2	2000	PWR (Millstone-2)	1988	Wet	
• INEL, DOE	TAN	?	BWR and PWR	1988	Dry	Supported by Waste Fund.

(a) Consolidation ratio of 2:1 achieved in one canister with rods from 2 of the assemblies.
(b) Western New York Nuclear Service Center, operated by West Valley Nuclear Services, Co., Inc., for DOE. The West Valley facilities were originally built and operated by Nuclear Fuel Services (NFS).
(c) Idaho National Engineering Laboratory, Idaho Falls, ID.
(d) Test Area North (TAN).

The current base of underwater handling experience suggests that fuel assembly handling, rod removal, and rod consolidation can be accomplished without major difficulty or impaired safety to spent fuel operators or the public. Experience with fuel rod inspection and fuel assembly reconstitution indicates that only about six fuel rods (out of over 51,000 irradiated rods handled) have been broken; the rods were known failed rods or came from assemblies that were known to contain failed rods.[9,10] Acceptable dry storage conditions for consolidated fuel seem feasible but have not yet been demonstrated.[13] Any difficulty in meeting dry storage temperature limits in helium with consolidated fuel could be resolved by consolidating older, colder fuel. It will be important to monitor upcoming demonstrations involving spent BWR and PWR fuel to further define fuel rod integrity aspects of rod consolidation activities and to evaluate the effect of loose crud on consolidation operations. The potential for rod breakage is potentially higher for cladding with large defects, but a consolidation campaign is underway on relatively old fuel (1971-72 discharge) with cladding defects caused by fuel densification. To date, over 1000 rods have been consolidated without rod breakage. Handling and reconstitution experience with extended burnup fuel deserves some attention to prepare for future fuel consolidation campaigns.

POOL DECOMMISSIONING

A major spent fuel pool decommissioning is underway at the Western New York Nuclear Services Center. The storage pool served the Nuclear Fuel Services reprocessing facility. Table 4 summarizes fuel that has been in extended storage in the pool.[14] After storage for 12 to 18 years (12 to 18 years for BWR fuel; 12 to 15 years for PWR fuel), fuel assemblies were shipped back to the originating reactors. Satisfactory handling and shipping characteristics of the fuel after extended wet storage reinforces prior experience suggesting that Zircaloy-clad fuel does not degrade significantly during interim wet storage. In fact, numerous assemblies in the inventory were known to have cladding defects. They were stored uncanned without substantial impacts on pool operations.

The last fuel is scheduled for removal from the pool in 1986, to be shipped to Idaho for extended dry storage. The pool will then be utilized for temporary

TABLE 4. Spent Fuel Inventory at the Western New York Nuclear Service Center at West Valley, New York

Reactor/Type	Number of Assemblies	Exposures, MWd/MTU Average	Date in Pool[a] at West Valley	MTU	Reactor Discharge Date
Dresden-1/ GE-BWR	206	16,000	10/73-09/74	20.429	09/69
Ginna/ Westinghouse-PWR	121	21,000-10,000	02/73-06/73	46.156	03/71-05/72
Big Rock Point/ GE-BWR	85	11,300	02/73-11/74	11.130	06/68-05/74
Point Beach-1 and -2/ Westinghouse-PWR	114	32,000	07/74-05/75	43.017	09/72-03/74
Oyster Creek/ GE-BWR	224	21,198-13,260	01/75-12/75	42.756	09/72-04/74

(a) Facility operated during 1965-1971 by Nuclear Fuel Services Company, Inc. (NFS).

storage, handling, and size reduction of radioactive equipment. Decommissioning of the pool is expected to be completed in the mid 1990's.

SUMMARY

In 1986 wet storage continues to function as the only licensed spent fuel management method in the U.S.A. While dry storage is expected to be licensed in the near future, wet storage will remain the predominant U.S. storage method beyond the turn of the century. The Nuclear Waste Policy Act of 1982 and the Nuclear Waste Confidence Rulemaking have formalized and stabilized the policy and regulatory aspects of wet storage.

U.S. utilities, supported in some sectors by federal programs, have moved progressively to optimize utilization of wet storage at reactor pools. This paper summarizes several aspects of U.S. wet storage technology, including the following elements: dense racking; double tiering; credit for burnup; potential influence of extended burnup; rod consolidation; and pool decommissioning.

With some 44 years of U.S. experience, wet storage technology is regarded as a mature and successful fuel management method, which is expected to remain in service as long as LWRs operate.

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