WHAT SHOULD I DO WITH MY SPENT FUEL?

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ABSTRACT

Over the next 15 years many of the utilities owning nuclear power plants face the challenge of significantly increasing the capacity of their on-site systems for storage of spent fuel. Three of the principal options available to the utility are discussed in this paper: 1) expanded pool storage systems, 2) new modular storage systems and 3) consolidation of the spent fuel for either pool or modular storage systems. The comments are based on operational experience at General Electric Company in the storage and transportation of spent fuel and the results of preliminary studies on storage system designs.

INTRODUCTION

With the advent of the Nuclear Waste Policy Act of 1982 (NWPA), it became clear that the utility owning a nuclear power plant will be responsible for storage of all its spent fuel until at least 1998 [1]. At that time, the U.S. Department of Energy (DOE) is scheduled to begin taking responsibility for disposition of spent nuclear fuel. Meanwhile, a number of utilities will have to increase their on-site storage capacity. How best can the utility meet this challenge?

Our purpose in this paper is to address this question by outlining the options available to the utility and commenting on their relative merits as we see them from two perspectives: 1) our operating experience in the transportation and storage of spent fuel and 2) the results from preliminary studies we have conducted on storage system designs.

OPTIONS AND UNCERTAINTIES

The utilities have a number of options available for interim storage of spent fuel. They also have a great number of uncertainties and constraints. The principal options are 1) expanding the capacity of the existing at-reactor pool storage systems, 2) providing at-reactor modular storage systems and 3) storing spent fuel in either type of system as intact assemblies or as consolidated fuel rods. Other options include trans-shipment to other reactor storage pools or to an away-from-reactor storage system (such as the GE facility at Morris, Illinois), transferring spent fuel to the DOE and constructing new independent storage facilities. These additional options appear limited in the extent to which they will likely be applied due to limited capacity, high cost or public pressures against transportation of spent fuel. We thus plan to limit our discussion to the three principal options.

The principal uncertainties and constraints relate to how much additional storage capacity will be needed, how much lead time is necessary to implement the program to provide additional storage capacity, how long will the storage facility be in service, what requirements will be in effect at the time the spent fuel is to be removed from storage, how will these requirements impact storage system design and operation and finally what are the physical constraints that existing facilities impose on the design and operation of additional storage systems. The latter is the easiest and will be the first to be addressed. The former, however, are impacted by forces outside the control of the utility, namely the requirements of DOE and the regulations of the Nuclear Regulatory Commission (NRC).

In the NWPA Congress divided responsibility for management of spent fuel and in effect set up two operating systems. DOE is responsible for final disposition of spent fuel, including transportation and geologic disposal, and "following commencement of operation of a repository" will take title to the material "as expeditiously as practicable" beginning not later than January 31, 1998 [1]. In the interim the spent fuel owners are responsible for storage of the material until DOE comes to the site and takes title (there is a provision for limited emergency storage by DOE but it is not expected to be used by the utilities).

The utility and DOE systems have a common interface at the transfer point, but otherwise can operate separately under different driving forces and schedule requirements. The DOE system for transportation, receiving, packaging, storage and disposal is not likely to be fully defined or finally approved by the NRC until the early 1990's. Prudent management or actual needs at many reactor sites, however, may well call for decisions on interim storage systems to be made before the DOE transfer requirements are definitively specified. Thus near-term storage systems optimum for reactor owners may not prove optimum for DOE's long-term system. Moreover, evolving NRC regulations and DOE requirements could result in multiple handling operations at the reactor sites if the interim storage mode is not directly compatible with the final DOE system. These uncertainties impact all the storage alternatives except for in-pool storage of intact assemblies.

POOL STORAGE SYSTEMS

The most straight forward among the interim storage options is to increase the capacity of the existing pool storage system up to its structural or economic limit. Many pools were designed and constructed with considerable margin in their floor loading. Some of the excess margin has been used by installation of high-density storage racks that in turn were designed with excess margin. Frequently the full amount of margin available in the system was not quantified in the original analysis. It was only verified that there was sufficient margin to meet the original design needs. Structural analyses must take into account the loads on the system and their behavior under potential seismic forces at the site; the analyses must thus be site specific and can be complex and expensive. Advanced structural analysis codes, which were not available when the original analyses were performed, can now be used to evaluate in a timely and cost-effective manner the potential stretch capacity of the pool system at a given site.

General Electric is currently applying these advanced analytical methods to several BWR pool storage systems. Seismic/structural analyses are underway to assess the capabilities of the pool floor and the high-density rack systems to support the extra weight associated with storing consolidated fuel. The fuel rods from two assemblies are assumed to be stored in the space formerly occupied by one assembly. The results from the analyses conducted to date, along with thermal/hydraulic and criticality/shielding calculations, are very encouraging.

The seismic/structural analysis of the base slab at the pool floor is based on the "strength design" method given in the concrete code published by the American Concrete Institute with the load combinations modified in accordance with the NRC Standard Review Plan [2,3]. The effects of the loads on the edge and center of the slab are derived from standard methods refined with a finite element plate analysis using ANSYS, a nationally known code published by Swanson Analysis Systems, Inc. [4].

In our analysis of a specific pool floor case, the first step was to calculate the floor reactions assuming a homogeneous, uniformly loaded base slab. For consolidated fuel loadings, the flexures at the slab center and edge showed an ample margin of safety but the shear margin at the edge was slightly negative. The next level of refinement was to model the pool floor and the building walls to give proper interactions using homogeneous shells with thicknesses based on strain equivalence with the actual rebar/concrete arrangement. The third level of refinement is to evaluate the effectiveness of shear resistant stirrups in the slab using a special reinforced-concrete element recently incorporated in ANSYS (revision 4.1B, March 1, 1983). Results from a benchmark beam bending problem correlate very well with expected results for stresses and deflections. Application of the ANSYS code to an integrated floor-wall model with a plate analysis that includes rebar elements and discrete loadings is expected to show a positive margin of safety for this particular pool floor when it is loaded with consolidated fuel under the site-specific seismic conditions.

Seismic/structural analyses are also underway to establish the practicality of storing consolidated fuel in the high-density racks designed and fabricated by General Electric for BWR pools. The GE high-density storage system is made up of free-standing modules. Each module consists of a checkerboard matrix of square tubes, fuel support plates and a base grid assembly. Each fuel storage tube is fabricated from an inner and outer stainless steel tube with neutron-absorbing material in between. The tubes are welded together, closure plates are spaced along the periphery and stiffening bars are welded to the underside of the fuel support plates, all providing rigidity to the module. The module support structure consists of a support base and a slider pad assembly. The support base is placed directly on the pool floor liner and is provided with a smooth top surface for contact with the slider pad. The slider pad assembly is bolted to the corner support plate of the module and contains a carbon-based material that permits the module to slide in an earthquake if sufficient forces are generated to overcome friction resistance.

Analysis of the storage rack system involves:

1) determining the seismic response spectra and time histories for the equipment at the specific site and defining structural damping values;

2) developing a two-dimensional "beam and lumped mass" model with matching frequency and inertial properties and adding the hydrodynamic virtual mass friction and gap elements for slipping surface characterization;

3) performing seismic time history analyses (using the ANSYS code) to calculate a) internal load responses, b) reactions to support structure and pool floor, c) displacements or the clearance between modules and d) vertical uplift or tilting potential of the module; and

4) evaluating the internal load distribution for stresses in the module components and evaluating reactions for stresses in the slider pad and support base assemblies.

For the two site-specific conditions studies to date, the results show that the existing high-density fuel storage modules can be used for consolidated fuel if the support bases are modified. Replacing the existing support bases with stronger and stiffer bases will serve to support the increased reaction forces on the bases and at the same time increase the natural frequency of the module, including its base structure, and thereby reduce seismic response acceleration to levels where stresses on the module components are acceptable. Since the system is modular without any ties to the pool walls, existing racks can be emptied and removed individually and the support bases replaced as needed.

Expanding the capacity of existing pool systems appears as a viable alternative for many utilities. Quantifying the structural limitations of the system is thus the first step in developing a site-specific program for interim storage of spent fuel. If the analysis shows unacceptable margins, modifications to the structures may be practical or use of flotation devices to displace an appropriate weight of water may be feasible. Having defined the feasibility and cost of expanding the pool system, the next steps are to evaluate the relative economics and operational impact of dry modular storage and rod consolidation systems.

MODULAR STORAGE SYSTEMS

Dry modular storage systems are rapidly evolving as a practical option for interim storage of spent fuel at the reactor site after the pool capacity is exhausted and before the DOE takes title for final disposition. In such a system the spent fuel is transferred from the fuel pool to an on-site storage yard containing individual storage modules. A modular system has a distinct advantage over an independent storage facility in that the up-front investment costs are relatively low and incremental storage capacity can be added as needed. The latter feature is directly responsive to the uncertainties as to when the DOE will take title to the fuel at a given site and thus how much capacity will be needed.

The system involves a sequence of three simple operations: 1) transfer from the pool to the yard, 2) storage in the yard and 3) transfer from the yard to DOE. The technology is evolving whereby the individual operations could be served by one common module or by separate units optimized for each function.

A metal cask, for example, could conceivably be loaded with spent fuel in the pool, transferred to the storage yard, monitored during a multi-year storage period and transferred to DOE for shipment off-site without removal of the fuel. Such a system would appear practical based on the experience in Germany, where metal casks have been successfully developed, designed, tested, licensed and fabricated for shipping spent fuel from the reactor site and storing it in a central facility [5]. In the U.S. demonstration programs are underway that will qualify metal casks for both storage and transportation [6,7,8]. To a U.S. reactor owner such a scheme would have the advantage of a once-through operating sequence. There are uncertainties, however, particularly the potential for regulatory changes during the storage period that would preclude direct shipment and thus require returning the cask to the pool for unloading and inspection or transfer to the spent fuel to a DOE transportation cask. In addition, a dual-purpose store-ship cask could cost more than a store-only cask, resulting in a cost increment to the utility that could be deferred or avoided since DOE is prespnsible for transportation within the scope of the mill/kwh fee.

An alternative scheme is under development that relies on dedicated units for the sequence of operations in the system and defers the question of cask needs for off-site transportation until later [9]. The storage modules would be fabricated from concrete, thereby realizing a saving in incremental storage cost. A special transfer cask would be needed, however, with a consequent increase in the up-front investment cost. Some accommodation could also be required at a later date to interface with the transportation system set up by DOE, such as a field transfer to a specially adapted shipping cask or possibly the spent fuel would be returned to the pool for retransfer to a standard transportation cask. Depending on the volume of fuel to be stored and the interface arrangements with DOE, such a system could be the minimum-cost optimum for the utility.

General Electric has recently completed a series of preliminary concept studies for dry modular storage systems. The study was aimed at developing a set of functional requirements and evaluating alternative design approaches. The requirements analysis considered: 1) fuel parameters, such as form, burn-up and time since reactor discharge; 2) handling limitations, such as crane lifting loads and personnel exposure; and 3) licensing requirements, particularly for storage under 10 CFR 72 and transportation under 10 CFR 71. Eight metal cask and six concrete module systems were developed to a level of detail where productibility could be evaluated and fabrication costs compared.

Most of the module concepts were for storage of either 52 BWR intact assemblies or consolidated rods from 104 BWR bundles or 24 intact PWR assemblies or consolidated rods from 48 PWR assemblies. Current design burn-ups were assumed with 10 years cooling since reactor discharge. Hook weights for loaded modules were 100 tons or less, cask surface doses 70 mrem/hr or less and the maximum cladding temperature was less than 380 C. Different materials and fabrication methods were considered, including 1) single-pour-ductile cast iron, sectional cast steel and ductile cast iron, cast lead, and laminated steel metal casks with internal and external neutron moderation and 2) conductively-and convectively-cooled concrete bunkers and silos configured for ship or site fabrication.

Observations from the study are as follows:

1) the estimated fabrication costs for the cast lead and single-pour ductile cast iron concepts were roughly comparable;

2) the estimated fabrication costs for the remaining metal cask concepts were roughly comparable among themselves, but were some 20 percent higher than the lower-cost concepts;

3) internal neutron moderation in the metal casks appears to be more cost effective than external;

4) the spread in the estimated facrication costs for the concrete modules was about 30 per cent;

5) the estimated fabrication costs for the lower-cost group of concrete modules were more than 40 per cent lower than the lower-cost group of metal cask concepts; the comparison does not include the impact of the greater upfront investment cost for the concrete module system; and

6) small concrete casks capable of both storage and transportation may prove feasible and cost effective.

The technical and licensing aspects of dry modular storage in the U.S. are being evaluated in a series of cooperative demonstration programs among Carolina Power & Light, DOE, Electric Power Research Institute (EPRI), Tennessee Valley Authority (TVA) and Virginia Electric Power Company [6,7,8,9,10]. Early emphasis is on the storage of spent fuel bundles under a 10 CFR 72 license. Plans are to extend the program to storage of consolidated fuel and transportation of the casks under 10 CFR 71. DOE is also planning to develop and demonstrate a new generation of spent fuel transportation casks to meet the fleet requirements anticipated for 1998 when the Department is to begin taking title to spent fuel at the reactor sites and shipping it to DOE receiving and packaging facilities [11].

The outcome of these various programs will determine the availability and cost of the various metal cask and concrete module alternatives for dry modular storage. With such data in hand, the last step is to evaluate the relative economics and operational impact of rod consolidation for pool and modular storage systems.

ROD CONSOLIDATION SYSTEMS

Methods for consolidation of spent fuel are being actively developed as a means of increasing the capacity of both pool and modular storage systems. The process consists of disassemblying the fuel assemblies, consolidating the fuel rods in a canister for storage and compacting the scrap hardware in separate containers for storage or disposal. The target is to achieve a fuel consolidation ration of two, whereby the consolidated rods from two fuel assemblies would be stored in the space formerly occupied by one assembly. Compaction factors of at least 5 and preferably 10 are needed for the scrap hardware.

The feasibility of rod consolidation has been established in a series of development programs for both in-pool and hot-cell systems ranging from cold mock-up tests to a full-scale hot demonstration [12,13,14]. Programs are underway for additional demonstrations of rod consolidation by DOE, EPRI, Northeast Utilities (with Baltimore Gas & Electric) and TVA [15,16,17].

General Electric currently offers services for reconstitution of fuel, compaction of irradiated hardware and transportation in the IF-300 cask and is developing a system for rod consolidation. The key design requirement for the latter is to maintain close control of the long, flexible rods as they are reconfigured from a square array to a triangular pitch. Rebundling of the rods must allow for possible crossover of individual rod along the length of the bundle. Additional requirements are to separate the fuel rods from the assembly hardware, control dispersion of the particular matter deposited on the surface of the rods allow for stuck or damaged rods, compact the scrap hardware, and package the rods and scrap in suitable containers. For pool storage systems the canisters must fit into the square one-assembly spaces of a high-density storage rack. A similar geometry is currently planned for modular storage systems although different canister geometries could be selected for the DOE transportation casks.

A key issue impacting rod consolidation is disposition of the scrap hardware. There are three potential options; 1) transportation and disposal offsite in Low-Level Waste (LLW) facilities; 2) storage in the pool or modular system along with the consolidate fuel; or 3) storage in separate facilities on the reactor site. Off-site disposal of scrap hardware may be precluded by lack of available capacity in the LLW facilities or by activity levels of long-lived isotopes in some of the materials that exceed 10 CFR 61 limits. Storage in the pool or modular systems, however, displaces capacity for storage of spent fuel and thus calls for very high scrap compaction ratios in what is probably a non-optimum geometry. Storage in separate facilities at the reactor site calls for additional up-front investment or a separate modular storage system configured for an optimum scrap package geometry. On the other hand, scrap hardware stored at the reactor site could later be transferred to DOE along with the spent fuel starting in 1998 rather than be disposed of in a LLW facility [18].

Evaluating the economic and operational impact of rod consolidation on pool and modular storage systems is complicated by the uncertainties in storage system costs, availability schedules and interface requirements with DOE. Storing consolidated fuel in the pool has the distinct advantage of keeping the spent fuel within the existing facilities and not raising possible public concern over the presence of outside storage modules on the reactor site. Moreover, storing consolidated rods in the pool offers additional flexibility in responding to future requirements of DOE for title transfer and removal off-site, including significantly reducing DOE's transportation cost.

Consolidation spent fuel in the pool, however, can be a time-consuming operation requiring access to the pool system and may increase personnel exposure. The reactor owner has the option of purchasing a rod consolidation system that would be operated by plant personnel or contracting rod consolidation services from a vendor as he has done in past campaigns for fuel constitution (GE, for example, has reconstituted well over 1000 BWR fuel bundles). Depending on the system and the scrap disposal or storage requirements, the cost for providing additional storage capacity by the consolidation could approach the cost of providing incremental modular storage capacity, particularly as concrete units.

Cost estimates will not firm, however, until the licensing and demonstration programs are complete and market needs start to increase above the prototype level. Another two or three years should see the technology and licensing base established with significant capacity needs starting to be implemented by the end of the 1980's.

CONCLUSIONS

At the present time, pool storage of consolidated rods and modular storage of intact assemblies or consolidated rods appear as viable options to the utility. Programs are in place or planned to establish a suitable technology and licensing base, the results of which will determine the availability and cost of the various metal cask and concrete modules for storage. Interface requirements with the DOE need definition to assure smooth integration of the utility's at-reactor storage system and DOE's transportation, storage and disposal system. Prudent management would call for timely and systematic evaluation of these options, starting with structural analysis of the pool system for possible storage of consolidated fuel and continuing with analysis of the relative economics and operational impact of dry modular storage and rod consolidation systems.

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