TRANSPORTATION OF HIGH-LEVEL WASTE AND SPENT FUEL

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INTRODUCTION

To address the need for the safe disposal of spent nuclear fuel and high-level radioactive waste in the United States, the Congress enacted the Nuclear Waste Policy Act (NWPA) of 1982. The objective of the act, subsequently amended by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), is to provide for the permanent disposal of nuclear waste in a deep geologic repository. The NWPA assigned the responsibility for developing a Federal Waste Management System (FWMS) to the U.S. Department of Energy (DOE), and within DOE established the Office of Civilian Radioactive Waste Management (OCRWM) for that purpose.

The NWPA and the NWPAA both require the DOE to seek public involvement in developing the FWMS, which includes the transportation system. Both acts also require the DOE to use private industry to the maximum possible extent. The DOE issued two documents in 1986 to outline its transportation strategies with regard to a business and an institutional plan. The Transportation Business Plan (DOE/RW-0046, January 1986), describes the DOE's approach to acquisition of a transportation system. The business plan focuses on technical development of cask designs that could form the basis of a safe and efficient cask fleet. The Transportation Institutional Plan (DOE/RW-0094, August 1986), has been developed to form the basis for interaction among all interested parties in the development of the transportation system.

There are 121 nuclear facilities in the U.S. located on 75 reactor sites, and 1 storage site, from which spent fuel will be accepted by the FWMS. To meet the requirements of the NWPA, OCRWM is developing a system that is adapted to accepting and transporting the fuel to waste-management facilities. Commencing in 1998, the OCRWM transportation system, consisting of a shipping-cask fleet and support services, will deliver spent fuel from nuclear facilities to a Monitored Retrieval Storage (MRS) site, and later to a permanent repository. At present, neither a site nor a design for an MRS have been determined. Although a potential repository site has been identified at Yucca Mountain in Nevada, it is currently being evaluated and will only be used if determined to be suitable.

The focus of this paper is on the advanced technology cask system development program activities currently being conducted to meet the long term transportation needs for the FWMS. OCRWM is also planning to acquire a small fleet of casks that rely on current cask technology to meet the short term need for a 1998 initial operational capability. Pursuit of these two activities is to assure that OCRWM meets its responsibilities to have a transportation system available for use in 1998, and to facilitate system efficiency by use of high capacity casks. That is, current technology casks will satisfy the need for a transportation system start up beginning in 1998, while advanced technology casks will assure maximum efficiency of the matured transportation system.

Other elements comprising the transportation system are discussed briefly below. These include operational planning and support systems, economic and systems analysis, and institutional interactions.

OPERATIONAL PLANNING AND SUPPORT SYSTEMS

Spent fuel is currently transported on a very limited scale in the United States. While the associated operations themselves are not technically complicated, the development of the transportation system to meet the requirements of the NWPA will be logistically complex. The complexity results from the large number of waste generators the system must serve, and the many interacting schedules that must be developed and accommodated. The system must operate in a manner that ensures shipments can be made from multiple locations on a continuous basis for at least a 40-year period, even though the specific sites, equipment requirements, and payloads will vary. Operating within this framework, the transportation system will involve intricate procedures that will make possible many simultaneous and sequential shipping campaigns. To ensure the total system is adequately developed, and all of its functions are identified, a systems engineering approach is being applied.

In preparation for the 1998 shipping campaigns, OCRWM is reviewing management options and evaluating technical and procedural requirements. By 1994, plans call for determining the preferred option for managing the transportation system. Resolution of integration and interface issues, and analyses of the complexity of the logistics involved, are presently under review. Consistent with NWPA directives, OCRWM plans to use private industry to the maximum extent possible in its transportation operations.

ECONOMIC AND SYSTEM ANALYSIS

Economic and system studies are identified and implemented to address important program decisions. The information obtained from the studies is generally relevant to the development of one or more of the transportation subsystems. One such effort are the cask-specification studies. OCRWM plans to estimate and document spent fuel cooling time and burnup combinations which will result in minimum shipment numbers, evaluate the feasibility of blending pressurized water reactor (PWR) spent fuel in rail casks, and consider the potential of accommodating non-fuel bearing components in future cask designs.

OCRWM is also investigating reactor cask handling and transportation infrastructure capabilities through the Facility Interface Capability Assessment (FICA) and the Near-Site Transportation Infrastructure (NSTI) studies, both recently completed. FICA is an essential piece of information in cask/reactor interface assessment. Based on the results, OCRWM can now evaluate the ability of each reactor to handle various types of shipping casks (legal weight truck, overweight truck, 100-ton rail/barge, and 125-ton rail/barge). The report also indicates the types of administrative changes, licensing actions, or plant modifications that show potential to increase reactor cask handling capacity. The NSTI study determines the capabilities at each reactor site to ship by truck, rail, or barge by focusing on the transportation infrastructure from the reactor gate to the federal highway system and/or the nation's rail or barge networks.

Modeling activities include optimization reviews, cask life cycle cost, and intermodal analyses. Extensive documentation and verification activities are underway for all models in accordance with OCRWM's Quality Assurance requirements. Statistical development includes continued maintenance of the Transportation System Data Base (TSDB) as a standard reference document for the collection of assumptions for national transportation network analyses.

INSTITUTIONAL INTERACTIONS

The transportation program involves complex interactions with Federal agencies; state, local, and tribal governments; technical associations; utilities; the transportation industry; the media, and the public. OCRWM uses a variety of forums to interact with interested parties to address their concerns relative to the development of transportation institutional policies. These include regularly scheduled meetings, publications, and public information efforts. In coordinating the transportation program, OCRWM representatives meet regularly with numerous organizations such as the Edison Electric Institute/Utility Nuclear Waste Transportation Working Group, the Nuclear Waste Technical Review Board (NWTRB), and an entire network of interested parties. In addition, meetings of the national Transportation Coordination Group (TCG) are held regularly. Cooperation and interaction with other Federal agencies such as the Federal Emergency Management Agency (FEMA) and the Department of Transportation (DOT), avoid duplication of planning efforts and identify any regulatory issues that may affect waste transportation.

Another avenue to solicit public involvement in developing the transportation system is found in cooperative agreements with interested groups for studying and resolving regional or specific transportation issues. OCRWM has entered into these type agreements with several groups representing states and Indian Tribes, as well as professional and technical associations including the National Conference of State Legislatures, the Western Interstate Energy Board, the Southern States Energy Board, the Midwest Office of the Council of State Governments, the National Congress of American Indians, the Conference of Radiation Control Program Directors, and the Commercial Vehicle Safety Alliance. These groups assist in areas such as emergency response, state inspections, highway routing, pre-notification, physical protection, liability coverage, infrastructure improvements, and state, local, and tribal regulations.

CASK DEVELOPMENT

As Federal waste management system receiving facilities become available, OCRWM will need a fleet of shipping casks to carry spent fuel and high level radioactive waste from their present locations to the MRS and final repository. The casks will be rugged containers designed to protect public health and safety by meeting the Nuclear Regulatory Commission's (NRC) transportation rules and regulations (10 CFR Part 71). The NRC transport requirements are similar to those of the International Atomic Energy Agency (IAEA) (Safety Series No. 6).

To obtain these casks, OCRWM has undertaken a major effort in cask development. At present, the primary emphasis is on developing "from-reactor" casks suitable for shipping most of the spent fuel to either an MRS facility or a repository (Initiative 1 casks). Other types of casks that will be needed are those for shipping spent fuel from the MRS to a repository (Initiative 2 casks); casks for special spent fuel that cannot be accommodated in current casks (or those presently under development) (Initiative 3 casks), and casks for high-level waste (Initiative 4 casks).

Cask Design Characteristics

Because the amount of spent fuel to be shipped is significant, pursuit of a new generation of casks designed for older and cooler spent fuel than those currently approved by the NRC was considered beneficial to transport efficiency. In 1986, OCRWM issued a request for proposal (RFP) for design, development, and fabrication of these new casks. Five contracts were awarded in 1988 for two legal weight truck (LWT) and three rail/barge (R/B) casks. The scope of the effort was modified in 1990 by the termination of one R/B contract, and slowing the activities of one LWT and one R/B cask contract (subsequently terminated in 1991). The two current contracts are for the General Atomics (GA) LWT and the Babcock & Wilcox (B&W) R/B cask designs.

The Current Casks

There are basically four cask designs that are certified by the NRC and currently available for use: two are LWT designs, one overweight truck (OWT) design concept, and one rail cask. Specifications for these can be found in the latest version of the NRC's NUREG-0383, volume 2.

The two LWT casks are made of stainless steel and are circular cross-sectioned. They can carry either one pressurized water reactor (PWR), or two boiling water reactor (BWR) spent fuel assemblies. Both use external water filled tanks for neutron shielding. The older of the two, the NLI-1/2, weighs about

22,336 kg (49,250 lbs.), and uses a combination of lead and depleted uranium (DU) for gamma shielding. The other, the NAC-LWT cask, uses lead for gamma shielding. The NLI-1/2 is designed for 150 day cooled fuel; the NAC-LWT for 2 year cooled fuel.

The OWT cask design concept is embodied in the TN-8/8L and TN-9 cask designs. Both systems are steel and lead designs with solid polymer neutron shielding. The designs are for 150-day cooled spent fuel and have gross weights of 36,000 kg (79,380 lbs.). The TN-8/8L holds 3 PWR assemblies; the TN-9 holds 7 BWR assemblies.

The rail cask, the IF-300, is a 63,492 (140,000 lbs.) cask that can carry 7 PWR or 18 BWR assemblies. It is constructed of stainless steel and has a circular cross section. External water tanks and DU are used for gamma and neutron shielding. The IF-300 is designed for 120 day cooled fuel.

New Generation OCRWM Casks

To ensure transportation capability is in place in 1998 to accept and transport spent nuclear fuel to the waste management facilities, OCRWM is taking a two-phase approach to acquiring Initiative 1 casks. This will allow for timely procurement of casks, as well as providing the time needed to complete an independent assessment of high capacity casks and adjust as necessary. Phase 1 (near-term) is for the purchase of current technology casks. These are either new casks which use current technology, casks which currently exist, or enhancements to currently existing casks. To facilitate NRC certification, all Phase 1 casks will use design features and materials previously approved by the NRC. The DOE Management and Operating contractor (i.e.,TRW) will issue the RFP for the Phase 1 casks. This will be preceded by a Commerce Business Daily (CBD) announcement and a notice in the Federal Register. Phase 2 (long-term) is for the acquisition of those high capacity casks currently under development (i.e., GA 4/9 legal weight truck and the BR-100 rail/barge casks).

The new GA and B&W designs are constructed of stainless steel and are optimized for 10 year cooled fuel (they may also carry fuel that has been cooled for 5 years). GA uses separate bodies for their PWR and BWR casks, and each weighs approximately 28 tonne (25 tons). The GA-4 cask can carry 4 PWR assemblies; the GA-9 can accommodate 9 BWR assemblies. Both have square cross sections and use DU for gamma shielding and a solid borated polymer for neutron shielding. The B&W BR-100 is a 110 tonne (100 ton) R/B cask designed to carry 21 PWR or 52 BWR assemblies. It has a circular cross section and uses an internal borated cement layer for neutron shielding.

Basis For Improved Cask Capacities

A comparison of the capacities between the current and new generation OCRWM casks shows an obvious improvement. Although the large increases in capacities are a radical departure from previous experience, the technical reasons that enable such increases can be identified and explained. The high capacities achieved for the new generation casks are accomplished by optimizing designs to the characteristics of the spent fuel to be shipped, and by introducing innovative and efficient approaches. OCRWM's new generation of casks are being designed to NRC's current design standards and practices.

The greatest contributor to increased cask capacity is fuel age (i.e., time out of the reactor). Both the internal heat generation and radiation emissions decrease exponentially with age. For example, a 150 day cooled fuel assembly generates about ten times the heat of a five year assembly, and about twenty times that of a ten year assembly. The longer cooling time also significantly reduces gamma emissions, thereby reducing the heavy metal (e.g., lead or DU) needed for shielding. Because the spent fuel characteristics and the cask capacities are varied, a simple quantitative comparison based on fuel age is difficult. However, an estimate of the weight increase of the GA-4 cask, if it were modified to carry 150 day cooled fuel, can be provided for purposes of illustration. The combination DU-lead gamma shield used in the NLI-1/2 cask can be estimated as an equivalent DU shield of about 4-inches thickness. Increasing the GA-4's 6.73cm (2.65-inch) DU shield to 10.16cm (4-inches) would increase its 11,247 kg (24,800 lbs.) of gamma shield by about 5737 kg (12,650 lbs.) (neglecting corner effects).

Other contributors to increased cask capacities include burnup credit. Burnup credit accounts for the reduced reactivity of spent fuel in evaluating criticality safety. A study completed by Sandia National Laboratories (SNL) demonstrated the potential effect of burnup credit is significant in increasing cask capacities (SAND 87-0151). The OCRWM cask contractors have not used burnup credit to its maximum potential in their designs. They have applied burnup credit only to PWR fuel, and only accounted for relatively low levels of burnup in design safety. Therefore, on loading the burnup credit casks, one need only exceed a low burnup level. This results in fairly substantial safety margins because burnups are generally much more than the levels used in criticality safety analysis. This practice has enabled designers to space fuel more closely, and to simplify basket designs considerably by removal of so called flux traps.

Cask Weight Limits

Both GA and B&W are seeking to maintain the high capacities promised by their cask designs. The LWT cask being designed by GA must accommodate the system consisting of the cask, tractor, trailer, and any ancillary equipment carried on the transport system and remain within the LWT limit of 36,281 kg (80,000 lbs.). The R/B cask being designed by B&W must meet the 90,703 kg (200,000 lbs.) hook weight limit. Hook weight is based on a crane limit of 100 tons for a cask assumed fully loaded and filled with pool water (but with impact limiters removed). At the end of preliminary design, B&W reported the weights of their cask in the PWR and BWR lifting configurations as 199,500 pounds and 200,000 pounds, respectively. The BR-100 is currently being redesigned to a weight limit of no more than 87,982 kg (194,000 lbs.).

Regulatory Compliance

The OCRWM from-reactor casks are being designed to comply fully with current NRC requirements, practices, and recommended design standards. Therefore, if these criteria offer a measure of assurance that public health and safety are protected, then the new generation of casks being developed by OCRWM can be considered to be as safe as casks currently approved by the NRC.

The NRC offers guidance for compliance with their transportation regulations for containment through Regulatory Guide (RG) 7.4. RG 7.4 endorses an American National Standards Institute leakage standard (ANSI N14.5) for containment. ANSI N14.5 has been used by spent fuel cask designers as a basis for compliance with the NRC requirements. It will be used by OCRWM for their new generation spent fuel casks.

The NRC transportation regulations specify external dose rate limits for normal and hypothetical accident conditions. Shielding for current casks are designed to these standards, as will be the new casks. Current casks designed for short cooled fuel have only been used for shipment of fuel cooled for a longer period. As a result, experience with spent fuel shipments leads one to expect external dose rates far below regulatory limits. OCRWM cask designs are being optimized for cooler spent fuel, and will generally be near the regulatory limits for external dose rates. The fact that the external dose rates are close to the regulatory limits for the new casks should not be viewed as a design inadequacy, or a threat to public health and safety. It is simply the result of optimizing the designs to the specifications of the spent fuel that will be shipped. To assure proper loading of casks, thus avoiding higher radiation source strength and to preclude exceeding NRC's dose rate limits, external dose measurements will be made for each loaded cask prior to shipment.

Criticality is the onset of a self-sustaining nuclear reaction. While it is a goal in reactor operations, subcriticality is a must in cask design. Criticality can occur when there is sufficient neutron interaction within a system of fissile material so as many neutrons are made available in each time segment as are lost through absorption, leakage, etc. Commercial light water reactor (LWR) fuel generally has less than 5% fissile material. As the fuel is used, the fissile content reduces further. To achieve criticality in an array of LWR fuel (even for unused or fresh fuel) water must be present, spacing must be appropriate, and parasitic neutron absorbers and neutron leakage must be limited. To prevent criticality in a LWR system, one must simply keep it dry. Further margin is achieved by limiting fissile content, allowing neutron loss, and introducing neutron absorbers (poisons).

The new generation casks use the same approaches to criticality prevention as are used for current cask designs, with one exception. For a portion of the PWR inventory, the new designs will allow reliance on the reduced reactivity of burned or used fuel for criticality control. As mentioned earlier, this is burnup credit. Basically, the designer uses the reduced fissile content and buildup of internal neutron poisons (fission products) in lieu of external controls designed into the basket. Both systems are equivalent from a safety design standpoint. However, burnup credit introduces the possibility of loading unburned fuel, thereby reducing the criticality safety margin. A loading error does not in itself result in a criticality event. For LWR fuel, water must be present, and neutron loss sufficiently small. To restore the margins associated with the fresh fuel approach, OCRWM will use reactor fuel management methods backed by independent verification measurements of fuel loaded into burnup credit casks.

Structural design for the OCRWM casks is performed using NRC RG 7.6 and RG 7.8. The NRC RG 7.6 provides design rules for containment structures that are based on the American Society of Mechanical Engineers (ASME) boiler and pressure vessel codes. The design method is a conservative linear elastic design approach containing large safety margins imbedded into the code rules and practices. NRC RG 7.8 specifies load combinations that must be used to design spent fuel casks. Although the NRC does not have any regulatory guidance for thermal design, they have established a record of acceptable practices which are being followed by the OCRWM cask designers.

Testing Program

The extensive testing programs for these cask designs are significant contributors to both efficiency and safety. The contractors have been performing engineering tests of components and subsystems to enhance confidence in design data and, thereby, reducing uncertainties. Recognizing that safety margins are used to compensate for uncertainty or lack of knowledge, the result of the test program is a safer design with less reliance on large safety margins. In addition, scale-model design verification tests will be performed for each of the casks. Again, the result will be a higher degree of confidence in the design's performance and safety attributes.

CONCLUSION

The OCRWM transportation program is a multifaceted undertaking to transport spent nuclear fuel from commercial reactors to temporary and permanent storage facilities commencing in 1998. One of the significant ingredients necessary to achieving this goal is the development and acquisition of shipping casks. Efforts to design and acquire high capacity casks is ongoing, as are efforts to purchase casks that can be made available using current technology. By designing casks that are optimized to the specifications of the older cooler spent fuel that will be shipped, and by designing to current NRC requirements, OCRWM's new generation of spent fuel casks will be more efficient and at least as safe as current cask designs.