STATUS OF SPENT FUEL SHIPPING CASK DEVELOPMENT *

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ABSTRACT

Several new-generation shipping cask systems are being developed for safe and economical transport of commercial spent nuclear fuel and other radioactive wastes from the generating sites to a Federal geologic repository or Monitored Retrievable Storage (MRS) facility. Primary objectives of the from-reactor spent fuel cask development work are: (a) to increase cask payloads by taking advantage of the increased at-reactor storage time under the current spent fuel management scenario, (b) to facilitate more efficient cask handling operations with reduced occupational radiation exposure, and (c) to promote standardization of the physical interfaces between casks and the shipping and receiving facilities. Increased cask payloads will significantly reduce the numbers of shipments, with corresponding reductions in transportation costs and risks to transportation workers, cask handling personnel, and the general public.

INTRODUCTION

The Nuclear Waste Policy Act of 1982 (NWPA) authorized the U.S. Department of Energy (DOE) to establish a national system for the disposal of spent nuclear fuel and high-level radioactive waste from commercial power generation, and established the Office of Civilian Radioactive Waste Management (OCRWM) within the DOE-Headquarters (DOE-HQ) to carry out these duties. A 1985 presidential decision added the disposal of high-level radioactive waste generated by defense programs to the national disposal system. A primary element of the disposal program is the development and operation of a transportation system to move the waste from its present locations to the facilities that will be included in the waste management system. The primary type of disposal facility to be established is a geologic repository; a Monitored Retrievable Storage (MRS) facility may also be included as an intermediate step in the nuclear waste disposal process. This paper focuses on the progress and status of one facet of the transportation program--the development of a family of shipping casks for transporting spent fuel from nuclear power reactor sites to the repository or MRS facility.

BACKGROUND

The NWPA requires that the DOE use private industry to the fullest extent possible in developing a transportation system. Therefore, the DOE is relying heavily upon contracts with private sector companies to develop equipment and provide services for the future transportation system. In accordance with the intent of the NWPA, the DOE is also consulting with, and soliciting comments from, the private sector (e.g., private industry, State and local governments, Indian Tribes, and the public at large) in planning and policy development.

Cask Acquisition Strategies

The transportation systems acquisition task is divided into two phases. Phase I covers the development and acquisition of prototype casks that will be used to ship spent fuel and high-level waste to or between Federal facilities. The DOE will develop a transportation fleet and implement transportation operations during Phase II.

Phase I of the transportation systems acquisition task includes four cask development initiatives. Initiative 1 covers the development of spent fuel casks to accommodate intact fuel assemblies or consolidated fuel rods. These casks will be used to ship 75 to 85 percent of the spent fuel from commercial nuclear power reactors to an MRS facility or repository. These "from-reactor" casks are the primary focus of this paper. If an MRS facility is approved by Congress, a highly efficient rail shipping cask will be developed under Initiative 2 for shipments from the MRS facility to the repository. This MRS-to-repository cask will be tailored to the unique cask handling capabilities at these two Federal facilities and to the spent fuel processing and containerization options selected for the MRS facility. Initiative 3 will cover the development of one or more "specialty" casks for transporting: (a) limited-quantity spent fuel that cannot be readily accommodated in Initiative 1 casks, and (b) miscellaneous nonfuel reactor waste materials requiring repository disposal. A rail cask for defense high-level waste will be developed under Initiative 4, in accordance with a 1986 memorandum of agreement between the DOE Office of Defense Programs and the OCRWM. New cask development under Initiatives 2 through 4 will be contingent upon a reaffirmation that modification of existing cask designs (e.g., Initiative 1 cask designs) would not provide viable alternatives.

Organizational Responsibilities

Responsibility for transportation systems and technology development has been assigned to the DOE-Idaho Operations Office (DOE-ID) by the OCRWM. This responsibility includes cask engineering development, development of associated transportation system hardware and cask handling methods, cask certification by the Nuclear Regulatory Commission, prototype testing, and associated technology development. The composite of these activities is referred to as the Cask Systems Development Program (CSDP). The primary contractor organizations participating in the CSDP under DOE-ID direction are EG&G Idaho, Sandia National Laboratories, and several cask development contractors selected from private industry.

EG&G Idaho provides general support services for the CSDP. EG&G Idaho also performs a strong technical liaison role with the cask development contractors, conducts generic technical studies related to cask systems design (e.g., cask handling, intermodal transfer, etc.), and supports DOE-ID in the implementation of the quality management program. Another important function assigned to EG&G Idaho is the management of a Technical Review Group (TRG) of nationwide experts; the TRG was established specifically to review CSDP cask designs and design-related information.

Sandia National Laboratories (SNL) serves as the CSDP technology development laboratory, provides technical assistance, and addresses regulatory and technical issues that apply generically to the overall CSDP. Further descriptions of some of SNL's current activities are presented later in this paper.

Cask development contractors, selected from private industry, perform the actual cask design and development work. These contractors are responsible for the engineering, design, fabrication, certification, engineering testing, design verification testing, acceptance testing, and inspection services of contracted casks. Deliverable products include prototype casks, cask models, supporting design documentation, technical manuals, and NRC certificates of compliance required for cask use. Other specific technical and administrative responsibilities of the cask development contractors are defined in their contracts with DOE-ID.

DEVELOPMENT OF FROM-REACTOR CASKS

Previous transportation cost and risk studies have shown that development of a new generation of shipping casks is warranted for transporting spent fuel from commercial nuclear power reactors to a repository or MRS facility. Several types of spent fuel shipping casks, both truck and rail, already exist and have been used successfully for many years. However, these casks were initially designed for transporting relatively short-cooled spent fuel (e.g., 150 days following discharge from the reactor) to a nuclear fuel reprocessing plant. Since most of the spent fuel available for transport to a Federal storage or disposal facility will be aged ten years or more prior to shipment, significantly higher cask payloads (by a factor of three or more) are achievable within the same radiation and thermal limits. Higher cask payloads will result in reduced numbers of shipments, and corresponding reductions in transportation costs and in the public and occupational risks (both real and perceived) associated with spent fuel transportation.

In addition to maximizing cask payload, there are several other important objectives in developing the new generation of spent fuel shipping casks. Since the Federal receiving facilities will have high throughput rates, maintaining low cask turnaround times and occupational radiation exposures will receive increased emphasis; these factors are also important to reactor site personnel. Therefore, innovative cask designs are encouraged in order to achieve more efficient and safer cask handling operations. Standardization of the physical interfaces between the casks and the shipping and receiving facilities will also facilitate these operations.

The request for proposals (RFP) for Initiative 1 (from-reactor) cask development was issued in July 1986. This RFP solicited proposals for four types of from-reactor casks: (a) legal-weight truck casks, (b) overweight truck casks, (c) rail/barge casks (i.e., casks suitable for transport either on rail cars or on barges), and (d) transportable storage casks (i.e., dual-purpose casks which could be used for both interim storage at reactor sites and subsequent transportation). The DOE procurement strategy is to award more than one contract for each cask type. The purposes of this strategy are to diversify cask sources, provide multiple options for the cask fleet composition, and mitigate the potential adverse impacts of removing a single cask design from service.

In June 1987, two contractors were selected for legal-weight truck cask development [General Atomics (GA) and Westinghouse], and three contractors were selected for rail/barge cask development [Babcock and Wilcox (B&W), Nuclear Assurance Corporation (NAC), and Nuclear Packaging Corporation (NuPac)]. All five contracts were in place by July 1988, and the cask contractors are currently in the preliminary design phase.

Overweight truck cask development was included in the two legal-weight truck cask contracts, but work has been delayed pending further study of technical and institutional issues associated with overweight truck shipments. A decision to award contracts for transportable storage cask development has been deferred until the feasibility and probable role of this cask type become better defined.

Cask System Design Requirements and Guidelines

Cask development work under this program is not limited to casks, but instead covers cask systems. A cask system consists of: (a) the cask body, (b) a transport system (truck trailer or railroad car; barge design is excluded), (c) closure heads, (d) internal fuel support structures (basket, sleeves, and spacers), and (e) ancillary equipment. Ancillary equipment includes impact limiters, protective enclosures, lifting and tiedown devices, special tools, spare parts, and fixtures for cask draining, drying, filling with inert gas, and testing. Cask system development includes analysis, design, testing, certification, prototype fabrication, and thorough documentation.

The RFP for from-reactor casks included a statement of work, cask physical performance specifications, and cask interface guidelines. This information has since been incorporated into the cask development contracts. The cask physical performance specifications are divided into three categories; the contents of each category are summarized as follows:

- Baseline Requirements -- Cask designs shall meet all applicable regulations and must receive a certificate of compliance from the NRC. Transporter designs must be in accordance with U.S.

Department of Transportation and Association of American Railroad rules and regulations. All cask development activities shall be conducted under quality assurance programs that meet the requirements of 10 CFR 71 Subpart H and the ANSI/ASME quality assurance requirements of NQA-1.

- ALARA and System Optimization Requirements -- Cask designs shall maximize payload to the extent possible while remaining in compliance with other requirements and constraints. Capability to perform all cask handling operations by contact (i.e., "hands on"), remote, or remote-automated techniques shall be maintained. Casks and ancillary equipment shall be designed in accordance with as-low-as-reasonably-achievable (ALARA) radiation exposure principles on a total system basis. Cask turnaround times at receiving facilities shall not exceed 8 hours for truck casks and 12 hours for rail casks; corresponding limits at reactor sites are 12 hours (truck) and 18 hours (rail). Cask system components shall be designed to limit surface contamination and to facilitate decontamination. Handling and operational interfaces shall be standardized for all casks in a given weight class. Intermodal transfer capability (e.g., transfer from truck to rail) shall be included in all cask designs.
- Additional Design and Development Requirements -- Critical structural components shall undergo design verification testing; cask prototypes shall successfully complete operational and acceptance testing. Cask containment structural materials must meet consensus code requirements or be supported by independently verified test data. Casks shall be compatible with either underwater or dry (hot cell) loading and unloading methods. Where practical, casks shall be capable of accommodating special-case waste forms (e.g., failed fuel, hardware, etc.). Cask design life shall be 25 years, and transporter design life shall be 1,000,000 carriage miles. Casks and transporters shall be designed for ease of inspection, maintenance, and repair.

The cask interface guidelines provide design guidance and establish the degree of standardization required to achieve system efficiency, yet allow flexibility for design innovation. Some of the key topics addressed by the interface quidelines are as follows:

- Fuel assembly designs for which cask designs should be optimized; other limited-quantity fuel that should be accommodated if practical
- Ranges for fuel initial enrichment (3.0 to 4.5 w/o U-235) and spent fuel burnup (18,000 to 35,000 MWD/MTU for PWR fuel and 15,000 to 30,000 MWD/MTU for BWR fuel)
- Spent fuel age (10-year-age design basis; evaluate capability to accommodate 5-year-age with internal design modifications)
- Technical evaluations of nonroutine payloads (e.g., impact of failed fuel, consolidated fuel, short-cooled fuel, etc.)
- Containment, shielding, criticality safety, and materials compatibility guidelines
- Temperature and pressure limits
- Mechanical requirements for spent fuel protection
- Physical dimensions and operational requirements for casks and for cask/transporter combinations
- Crane hook weight limits (25 tons for legal-weight truck casks and 100 tons for rail/barge casks) and gross vehicle weight limits (80,000 lb for legal-weight trucks and 263,000 lb for railroad cars)
- Design guidelines for tiedown systems, lifting/handling systems, impact limiters, other ancillary equipment, etc.
- Design guidelines for cask loading and unloading, draining, drying, sampling, purging, cooldown, leak-testing, etc.

Preliminary Design Status

All of the five cask development contractors (two for legal-weight truck casks, three for rail/barge casks) are well into the preliminary design phase. Between the time that contracts were awarded and preliminary designs were initiated, all contractors completed administrative prerequisites required by the contracts (e.g., preparation of governing planning documents, kickoff meetings, start-work briefings, etc.). The initial quality assurance surveys of all contractors have also been completed. Since the start of preliminary design, each contractor has held one or more meetings with NRC personnel responsible for cask certification to discuss preliminary design concepts and plans for resolving cask certification issues. Review of draft preliminary design packages will be initiated as they become available, and is expected to begin in the spring of 1989 and be completed in late fall of 1989. The final design phase will be initiated by each contractor upon approval of the completed preliminary design report.

Currently planned legal-weight truck cask payloads are 3/7 (i.e., 3 PWR or 7 BWR fuel assemblies) and 4/9. The three rail/barge cask capacities range from 21/45 to 26/52. For comparison purposes, typical existing spent fuel cask capacities are 1/2 for legal-weight truck casks and 10/24 for rail casks. Thus it appears that the desired significant increase in cask payloads will be achieved.

The preliminary designs being developed by the five cask contractors exhibit both diversity in design approaches and design innovation; both of these attributes were encouraged by the initial request for proposals. A variety of structural and shielding materials are included among the five designs: (a) cask body materials include stainless steel, ferritic steel, and titanium, (b) both lead and depleted uranium gamma shields are used, c) internal baskets fabricated from stainless steel and aluminum alloys are being designed, and (d) neutron shielding materials include borosilicone, borated concrete, borated polyethylene, and a borated hydrogenous structural polymer material. Similarly, impact limiter design concepts include structures fabricated from aluminum honeycomb, balsa wood, and polyurethane foam. One cask design utilizes an innovative fastening device for the closure lid which may facilitate cask handling operations and reduce occupational radiation exposure. Another cask design employs a noncylindrical shape for the cask internal cavity which more closely conforms to the spent fuel array; this innovative design may enable an increased cask payload by virtue of the reduced cask body weight. Even though some of the materials and design concepts present in the five preliminary designs are novel and may require extensive justification during the NRC certification process, they offer potential benefits that warrant the additional effort.

Cask System Testing

Several types of testing activities will be performed in support of the cask system design and development process. The primary objectives of these tests are to verify engineering and safety analyses, facilitate the cask certification process, ensure that manufactured items comply with design specifications, and verify that the casks and associated ancillary systems perform their intended functions. Another benefit of the planned testing activities is increased public understanding of, and confidence in, cask operational and safety features.

Three types of testing fall within the responsibilities of the cask development contractors. The contractors are responsible for defining the specific tests that are needed, conducting the tests (or arranging for tests to be conducted by other organizations on a subcontract basis), and analyzing the test results. These three test categories are briefly defined as follows:

- Engineering Tests -- These tests are performed on nonstandard materials and components to characterize their performance in the specific cask application. Engineering tests might also be performed for standard materials which are being used in a unique configuration in the cask design. Some engineering tests are confirmatory in nature, in that they provide additional confidence in analytical results.
- Design Verification Tests -- Design verification testing is defined as those tests used to verify that the cask system design is capable of meeting the regulatory requirements for normal and accident conditions, as specified in 10 CFR 71. The regulatory test conditions to be considered include heat, pressure change, vibration, water spray and immersion, compression, penetration, drop, and puncture. Design verification testing is not required by the regulations, but is deemed necessary in cases where analytical methods are judged inadequate without verification by testing. To the extent possible, these tests will be conducted using 1/4-scale (or larger, with DOE approval) casks, and perhaps selected full-scale cask components.
- Acceptance Tests -- These tests are nondestructive evaluations performed on each full-scale cask prototype to ensure that fabrication was in accordance with design specifications and conditions specified in the cask certification application to the NRC. Examples of acceptance tests are weld inspections, pressure and leakage tests, and measurements of heat transfer and radiation shielding effectiveness.

When cask prototypes have been delivered to the DOE by the cask contractors, performance evaluation tests will be performed by the DOE and its contractors to evaluate overall cask system performance in cask fleet applications. Examples of the types of performance evaluation tests that may be performed include the sequential operations associated with cask loading and unloading, intermodal transfers, draining and decontamination operations, maintenance operations, automated handling tests, etc. Support and technical advice from the cask development contractors and from organizations responsible for cask system interfaces during the operations phase will be needed in the design and conduct of these tests. If the performance evaluation tests indicate that cask system design changes are warranted, these changes can be made prior to cask fleet procurement.

CASK SYSTEMS TECHNOLOGY DEVELOPMENT

The cask development contractors have the responsibility for developing cask designs and obtaining NRC certification of those designs. This responsibility includes evaluating and justifying the use of innovative design concepts and materials. However, some technology development tasks are of potential generic benefit to the entire CSDP, and can best be accomplished with a central focus by a DOE national laboratory. Several of the technology development tasks which are currently being performed by Sandia National Laboratories are summarized in this section.

Burnup Credit

A traditional approach to criticality safety in spent fuel shipping cask design has been to use a fresh-fuel assumption, i.e., to assume that the fuel has not been used in a reactor. This assumption is conservative, since the nuclear reactivity of fresh fuel is much greater than that of spent fuel. If credit is taken for spent fuel burnup (i.e., depletion of fissile material) in the criticality safety analyses, the shipping cask designer may be able to reduce or eliminate neutron absorber materials from the spent fuel basket and reduce the fuel assembly spacing. The potential benefits of a burnup credit approach include increased cask payload and simplified cask design.

The acceptance of burnup credit hinges on two study areas. One involves evaluating the burnup credit impacts on cask payloads and the associated improvements in transportation system efficiency and safety. The other study area deals with the development of measurement systems, operating practices, and calculational methods which will make the use of burnup credit acceptable from both regulatory and operational standpoints. It is important to ensure that the reduced degree of conservatism associated with using burnup credit does not result in reduced criticality safety. Although Sandia National Laboratories has the lead technology development responsibility for generic burnup credit studies, the individual cask development contractors have responsibility for decisions on whether to utilize burnup credit in their cask designs and NRC certification plans.

Source Term

Applicable NRC regulations and regulatory guides show recognition that absolute cask containment (zero leakage), if achievable, cannot be demonstrated because of inherent limitations in leakage measurement capability. Two alternative approaches for determining the maximum allowable leakage rate from spent fuel shipping casks are permitted. In one approach, the allowable leakage rate is determined based, in part, upon the amount of radioactive material inside the cask which is available for dispersal (the source term). The other alternative approach is to show the cask to be essentially "leak-tight" by showing that the maximum air (or helium) leak rate, under specified conditions, does not exceed a specified value. The leak-tight approach is more conservative than the source term approach if only a small fraction of the contained radioactive material is in a dispersible form.

The primary objective of the source term technology development task is to develop standardized methodologies for evaluating compliance with cask containment requirements using a source term approach. These methodologies will be in the form of computational models capable of identifying, quantifying, and characterizing the dispersible radioactive material available for release from the cask to the environment. Residual cask contamination and "crud" adhering to external surfaces of the spent fuel assemblies are being considered, in addition to potential leakage from the fuel assembly cladding.

Cask development contractors are currently designing their casks to satisfy a leak-tight criterion, while keeping the option open to convert to a source term approach at a later time. Use of the source term approach would have little, if any, impact upon cask design, but could offer significant operational advantages in terms of reduced time, cost, and occupational radiation exposure associated with leak testing and cask maintenance activities.

Computer Code Benchmarking

Various computer codes are used during cask design and certification to predict and evaluate the performance of shipping casks under normal and accident conditions. Examples of technical evaluations that are normally performed with the aid of computer codes are thermal performance, structural response to nonroutine loadings, and criticality safety. To ensure that a computer code will yield accurate results for the problem being analyzed, the code is tested on a series of standard problems with known results. Showing that the computer code's results compare favorably with known results obtained by other methods is known as "benchmarking" the code. Experimental verifications are included in the benchmarking task as necessary.

Specific activities currently being performed under this task focus on structural design and thermal codes. The areas of interest include small and large strain problems relating to cask body behavior and thermal problems associated with phase change and multidimensional radiation.

Materials and Component Development

The responsibility for materials qualification and cask component development generally lies with the cask development contractor. However, there are specific instances in which the data needs of several cask designers can be satisfied more effectively by a central investigating agency rather than multiple cask development contractors. This centralized approach can also be used for independent verification of cask contractor results. In some cases, generic long-range work on materials and component development may be warranted for possible use in future cask designs, rather than in the from-reactor casks currently being developed.

Current materials evaluations and data compilation are being performed for depleted uranium, aluminum, low alloy ferritic steel, and borated stainless steel. Examples of cask components being studied are impact limiters (analytical and experimental data bases), gamma shields (evaluation of lead slump and depleted uranium cracking under accident conditions), and cask closure seals (evaluation of material properties).

Other Technology Development Activities

Additional generic technology development and technical support activities are currently being performed, and the list of specific activities may grow as the program progresses. An investigation of cask "weeping" (an apparent increase in cask surface contamination during transport) is in progress which may provide generic guidance to cask contractors on design features that mitigate this phenomenon. Specific applications of robotic technology for remote cask handling have recently been demonstrated. General technology transfer is an ongoing activity which is being performed to ensure that all of the cask development contractors have equal cognizance of available information pertinent to cask design and development.

CONCLUSIONS

The new generation of spent fuel shipping casks currently being developed will have significantly higher capacities than existing casks, which will result in a reduced number of shipments and corresponding reductions in transportation costs and risks. The diversity of designs being developed will provide numerous options for the cask fleet composition, flexibility in transportation operations, and contingency positions in case of problems with a particular cask design. Several innovative design features will potentially contribute toward cask payload optimization, improved cask handling operations, and reduced cask turnaround times and occupational radiation exposures. Results from the cask systems technology development tasks show promise for further improvements in cask design and operation and in the technical bases for resolving NRC certification issues. The current design development and technology development work is also expected to benefit future cask designs for other waste forms.