Packaging of Radioactive Wastes for Geologic Disposal

Hugh A. Benton
Framatome Cogema Fuels
Las Vegas, Nevada USA

ABSTRACT

The Management and Operating Contractor for the DOE Office of Civilian Radioactive Waste Management is developing designs of waste packages that will contain various types of nuclear waste: spent fuel assemblies from commercial reactor plants, Navy nuclear-powered surface ships and submarines, DOE-owned spent fuel from civilian and government programs including some assemblies from foreign research reactors, as well as high-level wastes vitrified in glass. The safe disposal of this nuclear waste so that it will not harm future generations requires both natural and engineered barriers to prevent the release of radionuclides.

This paper addresses the technical aspects of disposing of these wastes in robust packages and the use of other engineered systems, particularly focusing on the advances in design that have been made in the past year. The paper reviews the evolution of the waste package and engineered barrier design, and discusses the current status and rationale. In addition, the key engineering and regulatory issues that have guided the development are discussed along with the reasons that the long-term performance is expected to meet the requirements.

INTRODUCTION

TRW Environmental Safety Systems, Inc. (TESS) and its teammate companies form the Management and Operating Contractor (M&O) for the Department of Energy's Office of Civilian Radioactive Waste Management. The team has been active for more than six years in the program to manage commercial and some government-owned nuclear waste, including ultimate disposal in a geologic repository. One of the major activities involves designing containers to hold the various waste forms and developing materials and a system of multiple barriers to absorb, retard, and diffuse radionuclides. The waste forms to be disposed of include spent fuel from commercial nuclear power plants; high-level waste from defense programs; and a wide range of government-owned nuclear waste material such as foreign and domestic research reactor spent fuel, reactor cores from Navy nuclear power plants, and other wastes stored at DOE facilities at the Savannah River Site in Georgia, Hanford in Washington state, and Idaho National Engineering Laboratory. The variety of waste characteristics requires a number of container sizes and types, and in some cases different methods of criticality and thermal control.

DESIGN EVOLUTION

During the past six years, the disposal containers have been developed in conceptual and preliminary design phases. The original concept for disposal of commercial spent fuel was to use stainless steel containers about two feet in diameter that would be emplaced vertically in sealed boreholes extending down from the floor of mined emplacement drifts. This concept envisioned that the emplacement drifts would be accessible so that personnel could monitor conditions for the fifty-year retrievability period required by the regulations. There were several disadvantages to this concept. The small diameter of the boreholes would not permit the heat from the spent fuel assemblies to be dissipated into the rock without overheating the fuel cladding and potentially destroying an important barrier to the release of radionuclides. Also there would be a high cost for the large number of containers and boreholes required for the 70,000 metric tons planned for disposal in the first repository. Finally, as the concepts of defense-in-depth and multiple barriers to radionuclide release were developed, it was realized that the engineered part of the system including the disposal containers should be more robust and remain intact for longer periods.

The current concept assumes that there will be no human entry into the emplacement drifts once the disposal containers have been set in place. The emplacement operation, monitoring, and possible extraction of one or more containers, will all be done remotely. This permits the disposal containers -- without extensive self-shielding -- to be placed horizontally in the drifts providing better dissipation of the heat, so each container can accommodate more spent fuel assemblies without exceeding the cladding or rock-wall temperature limits. The reduction in the number of containers has kept their total cost within reasonable bounds, while the expected performance has improved greatly through use of robust, bi-metallic designs. Capacities of disposal containers for other high-level waste forms have also been increased so that a single disposal container can accommodate five individual canisters of vitrified defense high-level waste plus a center canister for DOE-owned spent fuel including highly enriched uranium waste forms.

COMMERCIAL FUEL CHARACTERISTICS

Wastes for disposal come in many forms and disposal container designs must accommodate all of them. Commercial spent nuclear fuel comes from two basic types of reactors: pressurized or boiling water. Within each of these two categories, individual assemblies can vary widely in their heat output and potential for criticality. There are also differences in the length of the assemblies used in certain reactor plants.

The U-235 enrichment in fuel assemblies will continue to increase over time as fuel manufacturers accommodate the desires of the nuclear utilities for longer times between refuelings. The increased burnups result in higher heat output from the burned assemblies. Some assemblies, including some that have high initial enrichments, will have been removed from their reactors without being fully burned. For instance, the final fuel loading at the time a plant is decommissioned will likely include

part of the fuel that has been only partially used. These assemblies could cause a higher criticality potential (k effective) when placed in a disposal container with similar assemblies, and therefore, will require additional supplemental neutron-absorbing material or other criticality control measures.

For these reasons, variations in the basic design of the commercial spent fuel disposal container are required. Although the Nuclear Waste Policy Act as amended limits the amount of commercial spent nuclear fuel and defense high level waste in the first repository to 70,000 metric tons of uranium, our disposal container designs must accommodate the characteristics of all of the commercial fuel assemblies, since any of them could be included in the first 70,000 metric tons. Table 1 shows the various sizes and internal configurations necessary to dispose of all the commercial fuel considering type of assembly and length, criticality potential, heat output, and cost effectiveness. The table also gives the number of disposal containers in each category needed for an assumed waste stream totaling 63,000 metric tons.

Disposal Containers Type	Outer Diameter Meters	Outer Length Meters	Empty Mass w/o top lids Metric Tons	Loaded Mass Metric Tons	Number of Disposal Containers
21 PWR - without absorber plates or rods	1.67	5.34	33	51	1444
21 PWR - with absorber rods	1.67	5.34	33	52	120
21 PWR - absorber plates	1.65	5.36	32	50	2641
12 PWR - no absorber	1.30	5.34	22	33	390
12 PWR - absorber plates (South Texas SNF)	1.30	5.86	25	37	150
44 BWR - no absorber	1.60	5.34	31	47	696
44 BWR - absorber plates	1.60	5.34	30	46	2107
24 BWR - thick absorber plates	1.27	5.34	22	31	42
Commercial Canistered Fuel (Westinghouse 44 BWR Design)	1.95	5.66	32	69	Unknown

Table 1
Types of Commercial Spent Fuel Disposal Containers

DOE-OWNED SPENT FUEL CHARACTERISTICS

There are some 250 types of DOE-owned spent fuel that can be categorized as shown

in Table 2. Not all of the DOE-owned spent fuel will meet the disposal requirements of 10 CFR 60 without some form of treatment. Some of the fuel will be relatively benign and can fill the largest disposal containers. Also some is like commercial spent fuel and can be accommodated in disposal containers designed for commercial assemblies. However, a significant part of the DOE-owned spent fuel is highly enriched in U-235 requiring special considerations for criticality control. It is planned to place these fuel rods or clusters in canisters in the center of an array of five defense high-level waste canisters. The resulting disposal container will be slightly larger in diameter than the largest commercial fuel container.

Navy spent fuel is very robust, with generally high initial enrichments and burnups. This spent fuel will receive special evaluation and packaging considerations. Although weapons-grade plutonium is not currently in the baseline for geologic disposal, one option for disposing of this waste form is to place it in small canisters encased in canisters of vitrified high-level waste glass. These canisters would then be placed with other canisters in disposal containers. There are other variations in the waste forms that are, or could be, designated for disposal, requiring flexibility in designs of the internal baskets of disposal containers.

Categories of DOE SNF	Fuel Material	Enrichment Class	Uranium Content (MTHM)	Total Volume (m ³)
SRS & RRF	U-Al Alloy	HEU	211	352
Naval Reactor	(Classified)	HEU	65	888
Shipping Port	U-TH-O ²	HEU	43	31
Gas Cooled Rx	U-Th-C	HEU	28	293
FFTF	U-PU-O ²	HEU	11	17
EBR-II	U-Metal	HEU	11	185
TMI-2 Debris	U-oxides	LEU	82	129
N-Reactor	U-Metal	VLEU	2,105	206
Comm. LWR	U-O ²	VLEU	90	77
EBR-II Blanket	U-Metal	VLEU	65	74
Misc.	(Various)	HEU/LEU	26	62
TOTAL			2,735	2,315

Table 2
DOE-Owned Spent Fuel Categories

MATERIALS

As shown in Figures 1 and 2, two different metals are used for the disposal containers,

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As shown in Figures 1 and 2, two different metals are used for the disposal containers, forming two separate barriers to the release of radionuclides; a corrosion-resistant barrier inside a corrosion-allowance barrier. The mechanisms by which the two barriers will eventually fail are different - the outer corrosion-allowance barrier will be subject to general corrosion processes including aqueous corrosion and oxidation, while the inner corrosion-resistant barrier will be subject to localized corrosion, primarily pitting. Two different failure mechanisms will spread the total failures out over a longer period of time, thus reducing the number of failures and the release of radionuclides in any one period.

The reference design for spent-fuel disposal containers has 100 mm of carbon steel A516 for the outer barrier and 20mm of Alloy 625 for the inner barrier. The thickness of the inner and outer barriers together provide enough shielding to protect against radiolytic corrosion. However, the radiation dose rates in the vicinity of a loaded waste package without supplemental shielding will far exceed the limits for personnel protection. Personnel protection will be provided by shielding in the hot cells of the Waste Handling Building and on the vehicle that transports the disposal containers to the emplacement drift. Human entry into a drift containing waste packages would be precluded without extensive local protection both from the high radiation levels and the high temperature.

An option being considered is to include an outer coating of ceramic material to enhance the corrosion-resistance of the containers. The particular type of ceramic to be used and the application techniques have not yet been determined. The ceramic coating should be essentially impervious to water and should resist damage through handling, rock falls, or thermal expansion of the disposal container. The intent is to make the ceramic coating continuous by spraying over the closure weld area after the containers are loaded and sealed.

Figure 1
21-PWR Spent-Fuel Container

Figure 2
Defense High-Level Waste/ DOE SNF Container

longitudinal seams to form cylinders. The length of the rolled cylinders will be less than the finished container, so the cylindrical sections will be welded together. Then the outer container would be heated and the inner cylinder set into it. As the outer cylinder cools, tight mechanical contact is expected, which will provide galvanic protection to the inner barrier by the less-noble steel of the outer barrier. The bottom will be closed with two circular plates welded in place. This shrinking of the outer shell around the inner shell has been tested in a full-diameter mockup of the upper portion of a disposal container. The mockup will be used to prove the welding process used to attach the two separate lids and the non-destructive evaluation techniques to prove the validity of the welds. All of the welds in the as-manufactured and delivered containers will be stress relieved. However, the final closure welds cannot be stress relieved without damaging the spent fuel assemblies. These stresses will be minimized through the application of the narrow-groove welding process, and the effect of the residual stresses on the performance of disposal containers will be evaluated in the mockup.

EMPLACEMENT IN REPOSITORY DRIFTS

All handling of the containers will be by the outer shell extensions that protrude beyond the portions of the shell that form the corrosion-allowance barrier. Disposal containers loaded with spent fuel or defense high-level waste will be transported into the repository and placed on pre-positioned supports in the drifts. These supports will be close enough together that the disposal containers will rest on at least two, and usually three, regardless of where the disposal container is placed. This will provide the flexibility to vary spacing between containers based on individual container heat output, and would also permit repositioning the containers after initial emplacement.

A water diverter or drip shield could be placed over the disposal container after emplacement to prevent water that might drip or seep into the drift from coming into contact with the outer corrosion barrier. The drip shield would be made of long-lasting and impervious material such as sintered aluminum oxide or other ceramics. Although other configurations of drip shields are possible, the most practical would probably be those that fit directly around the top half of the disposal containers and use the strength of the containers for their support. It would be important to protect the drip shields and the ceramic coatings from rocks that will, over time, fall from the roof of the drifts. This might be done by backfilling the drifts with sand or crushed tuff before the repository was closed and sealed. Before the drifts could be backfilled, the heat output of the spent fuel assemblies would have to decay so that the blanketing of the containers with the low-conductivity backfill would not cause the internal temperatures to increase to the point of cladding failure.

CRITICALITY

Criticality will be prevented by adding of supplemental neutron absorbers such as boron

stainless steel plates or boron carbide control rods in those disposal containers having assemblies that have not been burned enough to preclude the possibility of forming a critical mass either in the intact or degraded configurations. Certain high-enriched waste forms may require filler material such as iron shot or depleted uranium in the disposal containers. Criticalities can be prevented as long as the disposal container remains intact and the fissile and neutron absorber materials retain their original configurations. After the waste package is breached, and assuming that enough water is available to at least partially fill it, the spent fuel and supplemental neutron absorber can degrade into a broad range of possible configurations. Under these conditions criticalities are possible although extremely unlikely. The very long timeframes during which the spent fuel will retain enough fissile content to form a critical mass and the uncertainties in environmental conditions thousands of years in the future, do not allow us to use a deterministic analysis to guarantee that criticalities are not possible. Probabilistic evaluations are appropriate to analyze conditions throughout the postclosure period when the waste packages and the emplacement drifts can no longer be monitored.

Should a critical mass form either in a degraded waste package, in the drift in the immediate vicinity of the waste package, or in an area outside of the drift, the increase in k effective toward a critical condition would be very slow. When k effective eventually reached one and the configuration of fissile material became critical, there would be a slight output of power that would raise the temperature of the surrounding water or silica that was providing the neutron moderation necessary for criticality. The effectiveness of the less-dense moderator would decrease, and k effective would drop below the critical point stopping the reaction. This sequence could occur a number of times, each critical event resulting in a reduction in the amount of fissile material available until the remaining material could no longer support criticality. Although each critical event would result in a slight increase in radioactive fission products, the overall effect on the repository performance has been shown to be negligible.

PERFORMANCE

Regulations require that the waste packages remain intact for a period of from 300 to 1,000 years. However, the current assumption is that the robust waste package designs will contain the waste for at least 3,000 years under expected environmental conditions. The extended containment period will prevent radionuclide release until after the short-lived isotopes have decayed and repository temperatures are again well below boiling. This will keep any water from contacting the waste form while temperatures and the oxidation rates of spent fuel are relatively high.

The combination of robust, dual-barrier disposal containers, with the additions of options such as ceramic coatings and drip shields, will ensure containment of the waste material for much longer than the required period. The design of this containment system is proceeding on schedule and will provide a viable method of disposing of the nation's spent fuel and other high-level waste. Of course the decision to build and operate such a system requires that the potential repository site be found suitable and

that the President concur. Finally, the Nuclear Regulatory Commission must grant licenses to build the repository and to permit the receipt and possession of nuclear waste. Although there are important steps still ahead, the goal of a safe and effective solution to the problem of nuclear waste is in sight.

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