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CURRENT STATUS OF WASTE PACKAGE DESIGNS FOR THE YUCCA MOUNTAIN PROJECT

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ABSTRACT

Conceptual designs for waste packages containing spent fuel or high-level waste glass have been developed for use in a repository at Yucca Mountain, if that site is determined to be suitable for a high-level waste repository. The basis for these designs reflects the unique nature of the expected service environment associated with disposal in welded tuff in the unsaturated zone, well above the water table. In addition to a set of reference designs, tailored to the expected conditions, alternative design concepts are being considered that would contain and isolate the waste radionuclides in a more aggressive service environment. Consideration is also being given to the feasibility of a concept known as "heat tailoring" that employs the thermal energy released by the wasteforms to enhance and extend the performance of the containers.

BACKGROUND

Prior to the enactment of the Nuclear Waste Policy Act (NWPA) of 1982 (1), initial investigations were underway on the Nevada Test Site and adjacent public lands aimed toward siting a high-level waste repository. These early investigations were broadly based, with several rock types and hydrogeologic settings under consideration. Therefore, it was not productive to consider specific waste package design concepts, because the long-term performance of waste packages is highly dependent on the properties and operative processes in the very near-field environment.

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At that time, the principal responsibility for waste package R&D was assigned to Battelle under a "generic" waste package program. Because siting investigations were also underway in basalts at the DOE Hanford reservation and at several salt sites, where the hydrogeology and rock properties were significantly different than those typical of the Nevada sites, most of the emphasis was on very thick-walled steel containers to withstand large hydrostatic or lithostatic loads. The local geochemistry of these sites was dominated by either strongly reducing conditions with substantial quantities of liquid water, or highly saline environments, under fairly high pressures, expected to contact the waste packages and establish conditions where both aqueous corrosion of containers and liquid transport of radionuclides were expected.

In that same timeframe, the Nevada investigations were being focused on the volcanic tuffs in the vicinity of Yucca Mountain, but a candidate repository unit had not been selected. When the waste package development activities for the Nevada site were assigned to LLNL in late 1982, both saturated and unsaturated repository horizons were under consideration. Shortly thereafter, the decision was made to take maximum advantage of the characteristics of the unsaturated zone, above the static water table, in the Topopah Springs member of the Paintbrush tuff under Yucca Mountain. This allowed the waste package effort to be focused on this unique environment and design concepts were developed that were appropriate to the expected conditions that would exist and processes that would occur there.

REGULATORY CONSIDERATIONS

The NRC regulations that establish the requirements for licensing disposal of high-level wastes in a geologic repository are contained in 10 CFR Part 60,(2). Several sections of the rule directly address criteria and performance objectives for the waste packages; others imply or infer requirements for the waste packages as components of a larger system, such as the engineered barrier system (EBS). In particular, Section 60.113 establishes two primary performance objectives for the EBS, which is defined as the waste packages and the underground facility. The EBS is to be designed, assuming anticipated processes and events, so that (a) containment of the waste within the waste packages will be substantially complete for a period of 300-1000 years following closure of the repository; and (b) following this containment period, releases from the EBS will be limited to 1 part in 10^5 of the 1000 yr inventory of any radionuclide per year. There is an exception for nuclides that are released at very much lower rates, and a provision for establishing other nuclide release rate limits on a case-by-case basis.

Based on the current data on the performance of the wasteforms, it now appears that the waste package design is being driven by the release characteristics of only a few nuclides. These nuclides include those that are gaseous, such as ^{14}C, ^{85}Kr, and ^{3}H; and those that are highly soluble or are readily available in the spent fuel grain boundaries or in the fuel pellet-cladding gap region. These include the short-lived isotopes ^{90}Sr and ^{137}Cs during the containment period, and ^{99}Tc, ^{129}I, and ^{135}Cs during the post-containment period.

Other sections of Part 60 that affect the waste package design include criteria that limit the amount of water, pyrophorics, and some other materials in packages; require that the wasteforms be solids and be placed in sealed containers; and require that the packages be capable of being handled, emplaced, and retrieved if necessary prior to permanent closure of the repository. In Section 60.21 there is a requirement for an assessment in the Safety Analysis Report of alternatives to major design features that would provide longer radionuclide containment and isolation. This assessment would include alternative waste package designs.

WASTE PACKAGE ENVIRONMENT

The unsaturated zone, in a relatively strong though highly fractured and porous rock like welded tuff, presents a number of unique opportunities and challenges to the waste package designer. Among these are:

- The intrinsic characteristic of the unsaturated zone that no head of water is exerting a hydrostatic pressure on the waste packages.
- Emplacement boreholes that are expected to be stable, due to the creep-resistant properties of the rock, even at moderately elevated temperatures. Therefore the weight of the overburden will not be exerted on the waste packages as a lithostatic pressure.
- A high matric potential, or suction pressure, in the microscopic pores of the rock retains liquid water that would otherwise flow through the fractures, thus minimizing the potential for water to contact the waste package containers or provide a medium to transport soluble radionuclides away from the packages and, ultimately, down to the saturated zone and away from the repository to the accessible environment.
- A vadose water chemistry that is in geochemical equilibrium with the local rock mass due to the very low (<1 mm/yr) downward flux as the water slowly migrates toward the water table.
- A high gas permeability in the rock fracture system that allows exchange of air between the repository and the immediate vicinity of the waste packages. This will assure that the local environment will remain oxidizing for extended time periods.
- The expectation of an elevated temperature environment around the waste packages for an extended period resulting from the radiative transport and deposition of radioactive decay energy from the wasteforms in the surrounding rock mass that has a relatively low thermal conductivity.

WASTE PACKAGE DESIGN CONCEPTS

The expected service environment described above leads to some logical conclusions with respect to waste package design concepts. First, the expected absence of significant external pressures obviates the need for thick-walled containers. The principal structural requirements are then imposed by the handling and emplacement factors. This implies that the quantity of material needed to provide sufficient structural strength for the containers can be reduced and opens the option to consider "premium" materials. In combination with the expected humid air, or very limited liquid water conditions, the use of metal alloys that are highly corrosion resistant, rather than corrosion-allowance type materials, becomes viable.

Early in the period following enactment of the NWPA, it was assumed that the DOE would recommend to the President that the high-level waste from DOE defense program activities be disposed of in the repositories to be developed for commercial spent fuel. That recommendation was subsequently made (3) and adopted. Therefore, at least two distinctly different waste package design concepts were needed, one for spent fuel and another for defense high-level waste (DHLW).

The canisters into which the DHLW borosilicate glass is poured are to be fabricated from 304L stainless steel in the case of the Defense Waste Processing Facility (DWPF) at the Savannah River Site, and will likely be similar for the production from the Hanford site. In addition, there about 300 West Valley Demonstration Project canisters, also similar to the DWPF product. The form and packaging of the product from the Idaho site has yet to be determined. Initially, consideration was given to directly emplacing the DHLW into the repository with no further packaging beyond the pour canisters. However, a closer look at the temperature-time history of the 304L pour canisters during the filling and subsequent cooling cycles indicates that the canisters will have been subjected to conditions under which sensitization may occur. This, coupled with the possibility of large residual stresses left in the canisters, led to a design decision to place the pour canisters into separate disposal containers prior to emplacement in the repository. In the interest of minimizing the potential for detrimental material interactions, an initial "reference" alloy for the disposal containers was selected to also be 304L.

With regard to spent fuel, it has been clear for several years that the repository will probably be required to package and dispose of a variety of fuel configurations. These are likely to include fully intact assemblies, consolidated fuel, and some failed fuel in shipping canisters. Until recently, the reference form for disposal has been consolidated fuel and the associated non-fuel hardware. The studies performed by DOE in support of the MRS Commission review indicate that this position may be reconsidered.

A design objective has been to minimize the number of different external package configurations, consistent with the recognized differences in fuel assembly cross-sections, lengths, and other wasteform characteristics. The Project has adopted a set of reference waste package conceptual designs that are described in the Site Characterization Plan (SCP)(4) and shown schematically in Figures 1 and 2. A different internal waste package configuration, that is optimized for intact fuel assemblies, but capable of accommodating consolidated fuel or failed fuel canisters, has been developed, and is shown in Figure 3. As can be seen, they focus on circular cross sections with thin-walled containers that are in the nominal range of 26-28 in. diameter. A nominal 3/8 in. wall thickness is indicated; this thickness will be finally determined based on the structural requirements, the properties of the material selected, and the fabrication processes employed. The lengths range from about 10.5 ft for DHLW packages to 15.6 ft for intact spent fuel packages. The existence of some longer fuel assemblies is acknowledged, but no specific designs for their disposal have yet been developed.

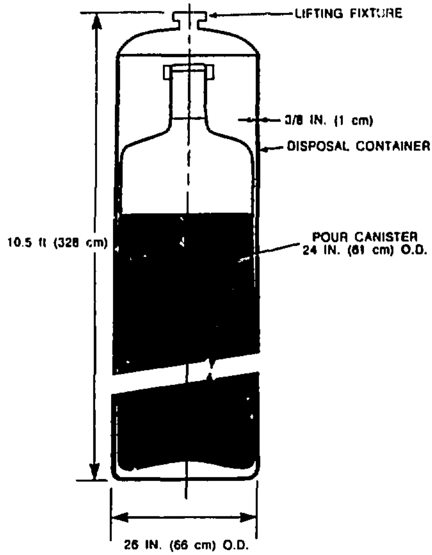

Figure 1. Reference Defense High-Level Waste Package

Thus far no specific container materials, other than the "reference" 304L, have been discussed. A broad spectrum of metal alloys have been considered for this application. The Project is conducting a formal material selection process, including independent peer reviews, at this time. The candidate materials have been reduced to six, three alloys with austenitic microstructures and three copper-based alloys. The selection criteria have been developed and the information needed to evaluate the six materials against the criteria is being assembled. A key part of this information pertains to the "as-fabricated" properties and localized corrosion characteristics of the materials. It is anticipated that this selection process will be completed within the next year.

ALTERNATIVE DESIGN CONCEPTS

It now appears that the ability of DOE to provide an analysis that will allow the NRC to make a finding of "reasonable assurance" that the performance objectives will be met by the waste packages will require that several components, including the wasteforms, will have to contribute to the containment and radionuclide release control. Tentative performance goals for each of these components have been established in the SCP, together with the bases for the goals. The data and predictive models to support a case that these goals can be met with high confidence does not yet exist. That confidence level will not be attained until the site characterization studies and other technical studies are near completion, several years in the future. It is therefore prudent to identify and develop one or more alternative design concepts in parallel with the reference designs. In addition, as noted previously, an assessment of alternative designs is a required part of the SAR and sufficient development of such designs to support that assessment is needed.

Three classes of alternative concepts have been considered: ceramic-metal systems, bimetallic and high-performance single metal systems, and coatings and filler systems. At this time, only very preliminary evaluations of these concepts have been undertaken. Resources are not currently allocated to this effort in order to expedite the completion of the material selection process for the reference design. Among the more attractive concepts, assuming that significant uncertainties in the fabrication and remote closure processing can be resolved, is a ceramic, perhaps alumina or titania, liner that could be installed either inside or outside a metallic structural member. The major advantage of this concept would be the high chemical stability in the near-field environment, even if that environment is determined to be significantly more aggressive than now expected.

HEAT TAILORING CONCEPTS

Another approach to enhancing and extending the performance of the waste package containers has received consideration. If implemented, this concept,

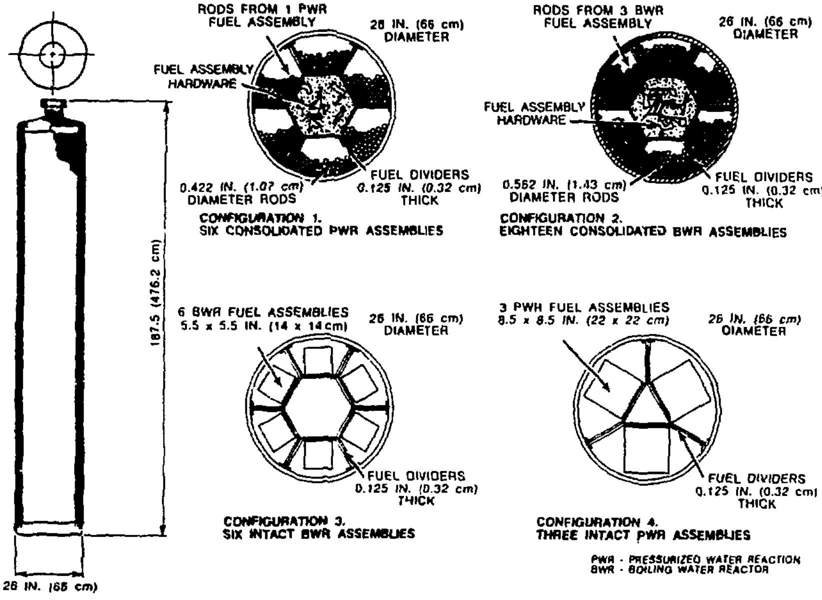

Figure 2. Reference Spent Fuel Waste Package

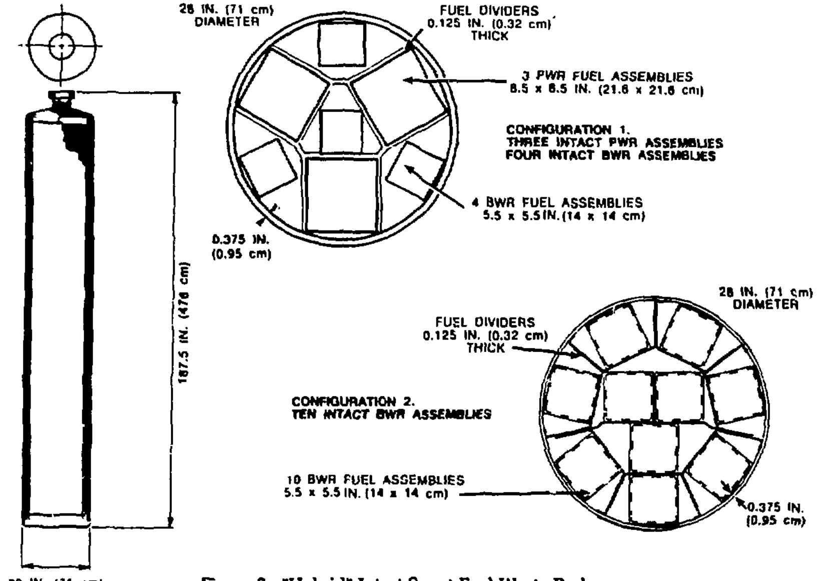

Figure 3. "Hybrid" Intact Spent Fuel Waste Package

known generically as "heat tailoring," takes advantage of the thermal energy released by the radioactive decay of the waste forms to maintain the temperatures at most emplacement hole walls above the unconfined boiling point of water in the unsaturated zone (about 97°C at the repository elevation) for several hundred years following waste emplacement. This establishes an environment around the waste packages that essentially precludes the presence of liquid water for an extended period. This thermal "barrier" is established by adjusting the spatial distribution of the energy deposition within the repository to compensate for the differences in the wasteform characteristics and geometric properties of a repository composed of a set of finite emplacement panels.

There are at least four different techniques that can be employed, either independently or in combination, to achieve heat tailoring. The first, called "receipt tailoring," is, in effect, an inventory management scheme. It depends on controlling the distribution of two key parameters of the spent fuel waste stream as it is received at the repository. These two parameters are age, or time since discharge, and burnup. Taken together, they determine the integrated energy that will be eventually released. By appropriately controlling them it is possible to produce a waste stream that will have a nearly uniform energy distribution throughout the spatial extent of the repository. By contrast, the energy distribution that results from a strictly oldest fuel first receipt scenario varies by more than a factor of three over the repository.

The second technique, called "geometric tailoring," utilizes modification to the emplacement panel geometry to adjust the energy distribution. By varying the geometric parameters such as emplacement hole and drift spacings it is possible to compensate for boundary effects near the perimeter of a panel and for variations in the waste characteristics. Limitations to this approach would exist based on minimum interhole spacings and minimum pillar dimensions as established by operational constraints and rock mechanics considerations. This approach can be very effective, but would require fairly detailed information on the waste characteristics well in advance of receipt (about two years) in order to adjust the panel designs as they are constructed in sequence prior to emplacement operations.

The third technique, called "package-scale tailoring," involves the selection of fuel based on its characteristics for individual packages and their positioning in the emplaced array to compensate for boundary effects on a local scale within a panel. This form of "fine-tuning" may well be operationally more difficult than is justified by the benefits, but it is certainly possible and may be useful in some instances. Limitations to this approach would come from constraints on the maximum thermal load within a single package or adjacent packages that could result in exceeding the allowable peak wasteform temperatures.

Finally, a fourth technique that could be used to tailor the energy distribution would involve different treatment of the spent fuel and DHLW wasteforms with respect to their locations within the repository. The conceptual repository design envisions commingling the two wasteforms in a disposal drift by alternating the emplacement of packages of each type in adjacent holes. Other schemes are equally credible, such as emplacing one wasteform or the other in a geometry that disperses it around the perimeter of a panel, or clusters it in the central region of a panel, or almost any other combination. Once the repository reaches a nominal "steady-state" receipt rate, currently planned to be 3000 MTU of spent fuel and about 800 DHLW packages per year (5), the permutations for geometric arrangements are very large.

SUMMARY

Some background and the current status of the reference and alternative waste package design concepts in support of the Yucca Mountain Project have been described. In addition, a set of possible techniques for enhancing and extending the performance of the containers by decay energy management have been discussed briefly. These design concepts will be the subject of more detailed studies and analyses, particularly as they affect the predictions of long-term waste package and engineered barrier system performance during the Advanced Conceptual Design phase that is scheduled to begin in the near future.

ACKNOWLEDGMENTS

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