THE REFERENCE WASTE PACKAGE DESIGN FOR A NUCLEAR WASTE REPOSITORY IN BASALT

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ABSTRACT

This paper describes the reference waste package design for the Basalt Waste Isolation Project. The waste form, functional requirements, and configuration for the reference design are described. A short horizontal borehole emplacement configuration containing a single waste package can meet the functional requirements during the operating, containment, and post-containment periods. The waste form will be placed in a thick-walled, carbon steel container. Surrounding the container is packing material made from a mixture of crushed basalt and sodium bentonite clay.

BACKGROUND AND DESIGN PHASES

The Engineered Barriers Department within the Basalt Waste Isolation Project (BWIP) of Rockwell Hanford Operations (Rockwell) has the ultimate responsibility for development and design of waste packages suitable for containment of nuclear high-level waste (HLW) in a repository constructed in basalt. These waste packages, according to current federal regulations[1,2] must successfully provide control of the waste for a period lasting 10,000 yr and isolate the waste from the groundwater environment for a period not less than 300 nor more than 1,000 yr after repository closure. Therefore, successful long-term waste package performance in the expected hydrothermal environment presents a significant engineering design challenge to the BWIP.

The engineering approach for this challenge is a systematic sequence of design phases: conceptual design, advanced conceptual design, license application, and final procurement and construction design. The present reference waste package design was developed for input to the advanced conceptual design. Presently, the waste package is defined in sufficient detail to allow decisions to be made among design alternatives on the basis of performance, cost, and schedule. Materials testing, development testing, and design analysis will be continued such that a firm basis will be available for the license application design that is scheduled to begin in 1988. Final procurement and construction design completes the process begun in license application design.

WASTE INTENDED FOR DISPOSAL

The reference waste package design was developed for the requirements of specific nuclear waste forms in a repository in basalt. The spent-fuel waste form is either fuel rods from disassembled fuel assemblies or intact fuel assemblies (commercial light-water reactors). The reference waste form for reprocessed wastes is vitrified waste (e.g., West Valley HLW or defense HLW). These waste forms will be enclosed in a thick-walled container to provide containment for handling and emplacement operations and substantially complete containment for at least 300 to 1,000 yr after emplacement.

WASTE PACKAGE FUNCTIONAL AND DESIGN REQUIREMENTS

The function of the waste package is to provide short-term containment and long-term control of the release of radionuclides (after breach of containment) in conformance with federal regulations[1,2] by employing an integrated system of physical and chemical barriers acting in concert with the host repository geology.

The functional requirements for the waste package components can be described best in relationship to three periods in repository history. The first period of the repository history is defined as the operational/retrieval period. During this 84-yr period, prior to permanent closure of the repository, the ambient geothermal gradient is perturbed by radionuclide decay heat. The waste package will experience its highest temperature, the ambient pressure will be near atmospheric pressure, and the environment of the waste container will be air and water vapor. The second period of the repository history is defined as the containment period, which continues for 1,000 yr after permanent closure of the repository. During this period, there is a pronounced reduction of heat generation by short-lived radionuclides. The third period, occurring after 1,000 yr, is defined as the period of limited release and is the remaining time of the repository history after assumed waste container breach.

DESCRIPTION OF THE WASTE PACKAGE ADVANCED CONCEPTUAL DESIGN

The reference waste package design is based on the short horizontal borehole (SHB) repository emplacement concept. The reference designs for the three waste forms considered during fiscal year 1985 are similar, varying only in the internal structure of the container and the waste package dimensions to accommodate different waste form sizes and corrosion allowances. For this paper, the discussion will focus on the design for the consolidated spent-fuel rods waste form.

The reference waste package design for consolidated spent fuel is shown in Fig. 1. The packing that is located between the container and a thin-wall, carbon steel emplacement shell becomes a low-permeability barrier when saturated. Packing helps to reduce the release rate of radionuclides to the geologic setting once the container barrier is assumed to have breached following the 1,000-yr containment period after repository decommissioning.

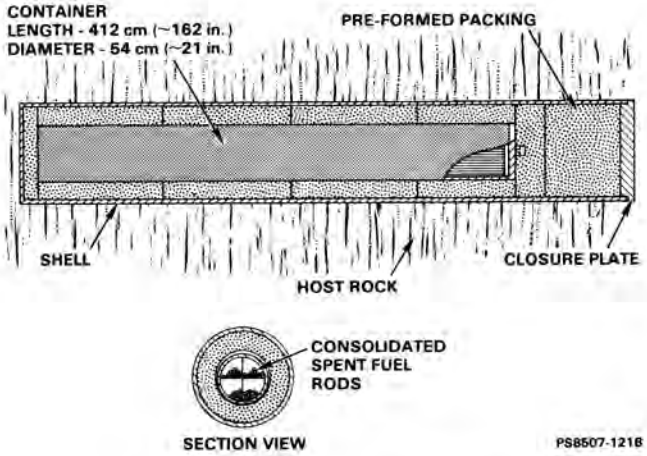

Fig. 1. Waste Package Design.

The container is designed to hold the rods from four pressurized water reactor (PWR) spent fuel assemblies based on design requirements developed by the BWIP [3]. Once the spent fuel rods are placed into the container, a closure head is installed and sealed by a welding process. The container wall is sized to resist the external loads expected to be present during the 1,000-yr containment period. The container wall thickness also takes into account corrosion including groundwater radiolysis. The container thickness is sized to reduce groundwater radiolysis to low values.

Consolidated Spent Fuel Waste Form.

The consolidated spent fuel (CSF) waste form, one of several waste forms considered, consists of fuel rods disassembled from four PWR spent fuel assemblies (SFA).

The typical maximum heat generation rate for the CSF waste form is 2,069 W for rods 10 yr out-of-reactor. Younger or higher burnup fuel would require a smaller amount of fuel per container to prevent exceeding the temperature limits on waste package materials[3]. Altering the internal structure of the container or adding a nonfissile filler, such as crushed basalt, would accommodate the smaller amount of fuel without changing the external size of the container.

This paper considers the specific waste form case of fuel rods from a Westinghouse PWR 15 by 15 fuel assembly. There are 204 fuel rods per assembly with an outside rod diameter of 10.7 mm (0.422 in.) and length of approximately 3.8 m (152 in.). The rods consist of irradiated UO_2 pellets contained in a Zircaloy-4 tube (cladding).

Consolidated Spent Fuel Container.

The container is a vessel fabricated from cast steel components. It is designed to resist both corrosion and external pressure, thus providing containment for 1,000 yr. Cast steel was specified by BWIP[3] because of its low cost, good weldability, and resistance to corrosion in the expected basalt geochemical environment. The inside dimensions are designed to be large enough to house 816 PWR rods with sufficient clearance for remote placement of the rods into the container during rod consolidation operations. A container wall thickness of 85 mm (3.35 in.) resists a uniform hydrostatic pressure of 9.4 MPa (1,363 lbf/in^2) without buckling and reduces groundwater radiolysis to low values. The general corrosion depth for the container was calculated using corrosion models and radiolysis criteria developed by BWIP.

The internals of the container are divided into four equal quadrants. Each quadrant is large enough to hold the rods from one PWR SFA. The quadrants are formed by a cruciform insert attached to the interior wall of the container. The material is carbon steel, similar in composition to the container material, to minimize the potential for galvanic corrosion.

The container is sealed remotely by making the final head/sidewall weld in a hot cell. Prior to sealing, the container is backfilled with an inert gas; e.g., argon. The inert gas provides a nonoxidizing atmosphere. Test results have shown that to preserve the fuel pellet UO_2 matrix structure and avoid degradation of the fuel cladding, a nonoxidizing environment is needed when storing fuel in a dry environment at temperatures above 400 °C [3]. The closure weld ensures containment of radioactivity and maintains the nonoxidizing environment.

A handling groove designed to interface with repository handling devices is provided at the closure head end of the container for handling. A pintle is provided on the container head for handling in the hot cell and for placement in the container. A pintle, which is machined from carbon steel bar stock, is welded to the head without compromising the effective container thickness. Lifting and handling of the container by the handling groove transmits the weight of the container and its waste form through the container body and not through its upper head. Thus, the closure weld is not subject to the structural loads of handling. The container design does not use lifting trunnions on the side of the container body as these would interfere with assembly. The handling groove would be used to grapple the container during any retrieval operations.

Consolidated Spent Fuel Packing.

The application of packing material surrounding the container reflects the current best estimates for the choice of the packing material and its properties. Further experimental data are needed to verify the packing material properties and the resulting packing thickness needed to perform its primary function of aiding the waste form in controlling radionuclide release to the host geology.

The reference packing material is a mixture of 25% sodium bentonite and 75% crushed basalt (by weight). The ultimate specifications for the materials to be used in waste packages will depend on the results of laboratory testing of the behavior and properties of the material and the results of process development tests on the manufacture and emplacement of the packing materials. The properties data from testing to date represent a variety of specific particle-size distributions for the bentonite and crushed basalt. The nominal value of packing material properties currently specified by BWIP[3] represents the average values obtained from tests of the current reference material. The choice of this material was based on engineering judgment that it will provide acceptable performance properties.

To ensure proper performance as a low-permeability barrier, the hydraulic conductivity of the packing material must be sufficiently low so that the mass transport of radionuclides is limited to diffusion processes. The functional design criteria[3] require an equivalent dry density of 1.7 g/cm^3 (106 lb/ft^3) for the packing material for in situ emplacement of the mixture.

The reference design uses preformed packing sections (precompressed packing material), which will result in void space because of the need to provide assembly clearances. The density for precompressed material was selected on the basis of ease of fabrication and by the judgment that the assembly tolerances will not result in a void volume greater than 10% of the packing volume. The value selected by BWIP is 2.0 g/cm^3 (125 lb/ft^3).

Consolidated Spent Fuel Waste Package Assembly.

Waste package components will be fabricated and assembled at various locations including the repository. Below-ground emplacement of the containers into the repository boreholes with preemplaced packing is the reference emplacement concept. Described here are the surface and subsurface assembly and handling operations necessary for emplacement of that waste package assembly.

After the container components are received at the repository, they will be stored until needed for assembly with the waste form/canisters in a hot cell.

A receipt inspection will be performed, and the components will be cleaned as necessary prior to being moved into the hot cell. In addition, the container components will be preassembled and serialized for package identification with the waste form/canister. All subsequent assembly operations are completed remotely in the hot cell because of the radioactivity of the waste form being packaged.

For the CSF waste form, the container must be compatible with the rod consolidation process. The container is remotely loaded with the fuel rods from consolidation. After the container is loaded with the waste form and inserted, the container head is lifted and set in place. Attachment of the head to the container body is accomplished by making a remote closure weld. Following the welding process, the weld will be inspected both by visual examination via remotely operated TV cameras and by ultrasonic examination. The loaded waste container is stored in the hot cell/lag storage for transfer to the borehole using the shielded transfer cask.

At a separate surface assembly area, the preformed packing sections are installed in the carbon steel shell. The shell/packing assembly is inspected by nondestructive examination, then transferred to the borehole and emplaced hands-on prior to emplacement of the radioactive-loaded waste container. This preassembly operation at the surface area reduces personnel radiation exposure and the number of surface operations. The shell functions to delay the packing from being exposed to an air-steam environment during the operational period. The shell is also a sacrificial component intended to withstand the abrasion from the borehole host rock when the package is slid into position.

The emplacement scenario described begins with the preparation of the access drifts and boreholes, before the packages are sent underground. Once the boreholes are excavated, the shell/packing assembly is emplaced. The loaded waste container is brought to the emplacement borehole from the assembly hot cell or from the lag storage area in a shielded transfer cask. The cask is aligned with the borehole, and the container is offloaded into the packing cavity.

Retrieval

Retrieval, if it should be necessary, would be performed prior to repository backfilling. The retrieval scenario will consist of removing the shell closure plate and outer packing sections and withdrawing the waste into a retrieval cask.

SUMMARY AND RECOMMENDATIONS

The initial design effort has shown that the SHB reference waste package design concept for PWR CSF rods has the potential to meet all requirements, based on available data and the analyses performed to date. These reference waste package designs for a national waste repository in basalt will enable the BWIP to further support the "Environmental Assessment" and the "Site Characterization Plan."

The initial design has provided new information regarding interface between waste package design and repository design and has supported the development of waste package criteria. Further, the reference design has identified the need for future investigations and development testing in specific areas regarding the performance and design of waste package containers and packing.

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