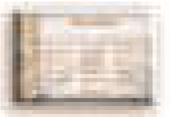

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Appendix E

Environmental Considerations for Alternative Design Concepts and Design Features for the Proposed Monitored Geologic Repository at Yucca Mountain, Nevada

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APPENDIX E. ENVIRONMENTAL CONSIDERATIONS FOR ALTERNATIVE DESIGN CONCEPTS AND DESIGN FEATURES FOR THE PROPOSED MONITORED GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

E.1 Introduction

E.1.1 OBJECTIVE

This appendix discusses design features and alternatives for a repository at Yucca Mountain in Nevada that were under consideration by the U.S. Department of Energy (DOE) in the winter of 1998 and early 1999. It represents a forward look at how the repository design might evolve to incorporate these and/or other features into a reference design that could be submitted in a repository license application. This appendix also addresses how this design evolution might affect parameters important to the assessment of environmental impacts. The design features and alternatives analyzed as part of the Yucca Mountain Site Characterization Project were conceptual in nature (that is, not developed or analyzed in detail). This appendix presents a qualitative description of the design features and alternatives and a brief assessment of factors associated with each that could cause changes to the environmental impacts analyzed in this environmental impact statement (EIS). This assessment generally indicates that the EIS reasonably represents the foreseeable evolutions in repository design related to environmental impact considerations and bounds potential impacts. Possible design evolutions that occur after DOE issues this Draft EIS will be factored into the Final EIS, as appropriate, and any such refined design concepts will be carried forward to license application if Yucca Mountain is determined to be a suitable site for a repository.

E.1.2 BACKGROUND

DOE has completed the *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998, all). The Viability Assessment included a preliminary design concept (referred to as the *Viability Assessment reference design* throughout this appendix), which presented preliminary design concepts for the repository surface facilities, underground facilities, and waste packages. The Viability Assessment reference design is the same as the high thermal load implementing alternative in the EIS.

Technical work associated with the Viability Assessment and the Viability Assessment reference design was not intended to support the selection of a repository design concept or specific alternative for licensing. Rather, the Viability Assessment identified areas requiring further study to determine site suitability to support a Site Recommendation and a License Application for a repository at Yucca Mountain. One area of further study and evaluation identified in the Viability Assessment was the assessment of alternative repository design features and concepts. The License Application Design Selection Process was established to study a broad range of alternative design concepts and design features to support the selection of the design to be incorporated into a license application.

The License Application Design Selection Process used a multistep approach for evaluating a selected set of features and alternatives against several criteria, including postclosure waste isolation performance, preclosure performance, assurance of safety, engineering acceptance, operations and maintenance, schedule, cost, and environmental considerations. In the first step, features and alternatives are evaluated against these criteria. Following this initial evaluation, enhanced design alternatives (which provide a unique approach to repository design and rely on the attributes of selected design features) were developed. In the development of enhanced design alternatives, there were no limitations placed on the development team to restrict consideration of features and alternatives to those on the initially selected list. From the inception of the License Application Design Selection Process, additional or evolved alternatives were expected to result. The process called for ranking of the enhanced design alternatives against a selected set of criteria using decision analysis methods. At the time of development of this appendix, enhanced design alternatives that were not part of the Viability Assessment had been developed, but documentation of that development and ranking had not been completed. Therefore, the information presented in this appendix is preliminary and based on both observations of the process and informal discussions with License Application Design Selection Process participants. This appendix will be revised as necessary to incorporate the final results of the License Application Design Selection Process. For the purposes of the License Application Design Selection Process, the following terms were defined:

- *Design Feature.* A design feature is a particular element or attribute of the repository design for which postclosure performance could be evaluated independently of a specific repository design alternative (fully developed design concept) or other design features. An individual design feature could encompass separate discrete concepts or a continuous range of parametric values. Design features can be added singularly or in combination to a design alternative. A design feature could theoretically be applied to any design alternative, although logical compatibility and expected postclosure waste isolation performance enhancement might be evident only when applied to particular design alternatives. Section E.2 of this appendix discusses the design features that were considered in the License Application Design Selection Process.

- *Design Alternative.* Each design alternative represents a fundamentally different conceptual design for the repository, which could potentially stand alone as the license application repository design concept. A design alternative can define major sections or the entire repository design. Design alternatives are distinguished from design features by their complexity and their inclusion of several features. Furthermore, a number of attributes are required to distinguish one design alternative from another. While not mutually exclusive, design alternatives represent diverse and independent methods of accomplishing the repository mission. Section E.2 discusses the design alternatives that were considered in the License Application Design Selection Process.

- *Enhanced Design Alternative.* Enhanced design alternatives are combinations (and/or variations) of one or more design alternative and design feature. While an enhanced design alternative could be made up of any conceivable combination of design alternatives and design features, enhanced design alternatives selected for further evaluation are those combinations that include mutually compatible attributes and expected postclosure waste isolation performance characteristics that exceed those of the basic design alternatives. In other words, the enhanced design alternatives are all improvements to the design alternatives in the first phase of the License Application Design Selection Process, including the Viability Assessment reference design. Other considerations in developing the enhanced design alternatives include the compatibility of the features and alternatives; the developmental, operational, and maintenance simplicity of the resulting combination; and the ability of the set of enhanced design alternatives to address the entire set of design features and alternatives under consideration.

Recommendations for the repository design concept that resulted from the License Application Design Selection Process will be part of a technical report scheduled for completion after this appendix was prepared. The design concept to be carried forward is expected to be one of the five enhanced design alternatives currently identified or minor variations of one of those enhanced design alternatives. Section E.3 of this appendix discusses the enhanced design alternatives that are the subject of consideration in the License Application Design Selection Process.

E.1.3 SCOPE

This appendix discusses the evolution of the EIS repository design concept to the concept that will ultimately be submitted as part of the license application for the Yucca Mountain repository, should the site be approved. The discussion is broken down into three basic categories that reflect the potential types of benefits from the design features and alternatives under consideration. The benefits that could be derived from each of the features and alternatives are not necessarily limited to the categorization presented, and some features and alternatives could fit into more than one category. However, the three categories were chosen to facilitate an understanding of the design evolution process that is presented in the main body of the EIS. Section E.2 discusses the set of selected design features and alternatives.

The categories, as presented in Sections E.2.1 through E.2.3, are Barriers to Limit Release and Transport of Radionuclides; Repository Designs to Control Thermal/Moisture Environment; and Repository Designs to Support Operational and Cost Considerations. Within each category, the text includes descriptions of the features and alternatives, explanations of why each feature/alternative was considered, and discussions of the potential for environmental impacts associated with each feature/alternative.

Section E.3 presents the five enhanced design alternatives that were considered in the first phase of the License Application Design Selection Process to develop a design concept for the proposed Yucca Mountain Repository that was an improvement over the Viability Assessment reference design. This improvement could take many forms, including enhanced licensibility, reduced uncertainty, and ease of construction and operation. The five enhanced design alternatives represent five complete basic design concepts that evolved from consideration of the features and alternatives discussed in Section E.2. The enhanced design alternatives were selected to represent the potential differences in waste isolation performance among differing repository designs. The participants in the License Application Design Selection Process determined that a major factor in selecting the final design for the Yucca Mountain Repository would be the thermal loading of the repository. As such, the five enhanced design alternatives represent a range of thermal loads from 40 metric tons of heavy metal (MTHM) per acre to 150 MTHM per acre. Important differences between the enhanced design alternatives and the Viability Assessment reference design include differences in waste package materials and the addition of a drip shield to each of the enhanced design alternatives. Each of the enhanced design alternatives was selected to improve on the Viability Assessment reference design from a waste isolation performance perspective. As was the case with the basic design features and alternatives discussed in Section E.2, there is the potential for environmental impacts associated with the enhanced design alternatives.

E.2 Design Features and Alternatives

E.2.1 BARRIERS TO LIMIT RELEASE AND TRANSPORT OF RADIONUCLIDES

E.2.1.1 Ceramic Coatings

A thin coating [1.5 millimeters (0.06 inch) or more] of a ceramic oxide on the outer surface of the waste package could increase the life of the waste package by slowing the rate at which the waste package will corrode. Candidate materials for the ceramic coating are magnesium aluminate spinel, aluminum oxide, titanium oxide, and zirconia-yttria. Spinel is the leading alternative.

E.2.1.1.1 *Potential Benefits*

The ceramic coating could increase waste package life and repository waste isolation performance by reducing corrosion of the waste package surface and, therefore, delaying the release of radionuclides.

E.2.1.1.2 *Potential Environmental Considerations*

There are no significant environmental considerations associated with ceramic coatings.

E.2.1.2 Drip Shields

Drip shields would provide a partial barrier by diverting infiltrating water away from waste packages in an emplacement drift. Drip shields could be metal (for example, Alloy-22, a nickel-chromium-molybdenum alloy, or titanium-7, a titanium metal alloyed with 0.15 percent palladium) or ceramic-coated metal. One option is to place drip shields under backfill; another is to place the drip shields over the backfill. Drip shields could be implemented with or without backfill.

If the drip shield was placed under backfill, it would fit over the entire length of each waste package, configured to the outer diameter with an unspecified clearance between drip shield and waste package, and enclosed at each end. Backfill, which would be emplaced during the repository's closure, would be comprised of a heaped, single-layered material that covers the waste package and drip shield to some unspecified depth. Another form of backfill, the Richards Barrier, could also be used. Backfill and Richards Barriers are discussed later in this appendix.

The drip shield, as used in the second option, is formed to the approximate backfill surface profile and placed atop the backfill (or Richards Barrier). With this option, the drip shield is placed in conjunction with the placement of backfill at the closure of the repository.

E.2.1.2.1 *Potential Benefits*

Drip shields are intended to enhance long-term repository performance by reducing waste package corrosion and extending waste package life.

E.2.1.2.2 *Potential Environmental Considerations*

Additional labor hours would be required for the generation and placement of backfill material, and industrial accidents could increase proportionately. Although drip shields would be emplaced remotely, there could be some incidental radiological doses to workers.

Drip shields of titanium-7, Alloy-22, or other corrosion-resistant material would increase the demand for such materials. Costs for repository closure would increase due to the cost of procuring and installing the drip shields.

E.2.1.3 Backfill

At repository closure, loose, dry, granular material such as sand or gravel would be placed over the waste packages in a continuous, heaped pile. Other materials for backfill, such as crushed rock and depleted uranium, may be evaluated in the future.

E.2.1.3.1 *Potential Benefits*

Backfill would provide protection of waste packages and drip shields (if placed over the drip shields) from rockfall. It could protect against corrosion of the waste packages by (1) potentially capturing the corrosive salts of various soluble chemicals that might enter with water intrusion, (2) retarding advective flow, and/or (3) increasing the temperature of the emplacement drift to decrease relative humidity.

E.2.1.3.2 *Potential Environmental Considerations*

Additional workers would be needed, and there would be a potential increase for industrial accidents because of the additional operations. Although backfill would be placed remotely, there could be some incidental radiological doses to workers.

E.2.1.4 Waste Package Corrosion-Resistant Materials

The Viability Assessment reference design for the waste package uses two concentric barrier layers: an outer 100-millimeter (3.9-inch)-thick A516 carbon steel structural corrosion-allowance material, and an inner 20-millimeter (0.8-inch)-thick nickel-based alloy-22 corrosion-resistant material. These two barriers would be expected to provide substantially complete containment of the waste for the lifetime goals established in the Viability Assessment; however, a waste package with the capability to provide substantially complete containment for a significantly extended lifetime would be more desirable.

A variation of the waste package design would replace the corrosion-allowance barrier with a second corrosion-resistant barrier. This design would provide in-depth defense if the second corrosion-resistant barrier was independent of the first (for example, made of a different metal or ceramic). A number of configurations of waste package containers with two corrosion-resistant materials were analyzed, including designs with an inner layer of titanium and outer layer of nickel-based Alloy-22, with a combined thickness of about 55 millimeters (2.2 inches).

E.2.1.4.1 *Potential Benefits*

Longer waste package lifetimes would lead to improved long-term waste isolation performance of the repository.

E.2.1.4.2 *Potential Environmental Considerations*

The addition of a second independent corrosion-resistant layer would prolong waste package lifetimes, resulting in delay and minimization of potential groundwater contamination.

Radiological dose to workers would increase without compensating changes in operating procedures, because the total thickness of the waste package container could be less than the Viability Assessment reference design. Appropriate shielding might have to be provided for the workers engaged in waste package handling and emplacement operations. However, there would be a potential increased occupational dose to the workers because the calculated dose rates at the waste package surface would be higher.

E.2.1.5 Richards Barrier

A Richards Barrier would be formed by placing two layers of backfill over the emplaced waste packages at closure. The barrier would consist of a coarse-grained, sand-sized material underlying a fine-grained, sand-sized material. Both materials would be placed as a continuous, heaped pile extending along the alignment of the waste packages. A variety of materials could be used for both layers, including depleted uranium as a coarse-grained material.

The Richards Barrier would be designed to divert water that might enter the emplacement drifts away from the waste packages by transferring the vertical migration of water seepage laterally along the interface between the two layers. The particle size distribution, shape, and porosity of material in the two layers would provide a permeability difference and would cause the upper layer to channel water seepage along the boundary of the lower layer.

E.2.1.5.1 *Potential Benefits*

The Richards Barrier would delay the transport of water to the waste packages, thereby delaying waste package corrosion and improving long-term repository performance.

E.2.1.5.2 *Potential Environmental Considerations*

Dust and equipment emissions could be a concern during the placement phase of the Richards Barrier.

If the chosen coarse material was depleted uranium, there would be an increase in radon emissions. Uranium might also lead to an increase in the contamination of groundwater because the uranium in the Richards Barrier would not be contained or restricted by other engineered barriers. Radiation exposure would also have to be considered in design and operations of depleted uranium handling.

Additional workers would be needed during closure to implement this design feature, and there would be an increased potential for industrial accidents. Although personnel would not be in the drifts, there might be some incidental radiation dose to workers outside the drifts; therefore, additional shielding might be required for personnel.

E.2.1.6 Diffusive Barrier Under the Waste Package

A diffusive barrier would consist of loose, dry, granular material placed in the space between each waste package and the bottom of the emplacement drift to form a restrictive barrier to seepage. Below a critical seepage flux, water would disperse throughout the porous medium of the diffusive barrier, providing both lateral vertical dispersion and thereby slowing the fluid movement to the natural environment. Radionuclides, which might be released from breached waste packages, could become solubilized or suspended within the seepage flow and be retarded by the porous material forming the barrier.

The diffusive barrier could be anything from common sand to gravel-size material without any special qualifications to mineralogy, grain size distribution, shape, or density. Depleted uranium could also be used. The diffusive barrier would be installed prior to waste emplacement.

E.2.1.6.1 *Potential Benefits*

Improved waste isolation performance could be achieved by slowing radionuclide movement to the natural environment.

E.2.1.6.2 *Potential Environmental Considerations*

If the diffusive barrier material were depleted uranium, there would be increased radon emissions and increased radiological dose to workers. There could be an increase in the contamination of groundwater because the uranium would not be contained or restricted by other engineered barriers.

Additional workers would be needed to construct the diffusive barrier; therefore, there would be a proportional increase in the potential for industrial accidents.

E.2.1.7 Getter Under Waste Packages

A getter would be a fine-grained material [either phosphate rock (apatite) or iron oxide (hematite, geothite, etc.] with an affinity for radionuclides. This material would be placed in the invert recess below the waste packages prior to waste emplacement.

E.2.1.7.1 *Potential Benefits*

A getter material below the waste packages could improve long-term waste isolation through retardation of radionuclide movement from the repository drifts.

E.2.1.7.2 *Potential Environmental Considerations*

Additional workers would be needed to place the getter material in the drifts; therefore, there would be a proportional increase in the potential for industrial accidents.

E.2.1.8 Canistered Assemblies

Placing spent fuel assemblies in canisters at the Waste Handling Building before inserting them into waste packages would provide an additional barrier and further limit mobilization of radionuclides if the waste package is breached. The canisters would be fabricated from a corrosion-resistant material (for example, Alloy-22 or a zirconium alloy). There are three general concepts for the placement of fuel assemblies in canisters:

- Rectangular canisters designed to hold individual fuel assemblies: these canisters could be placed into a waste package with a basket containing neutron absorber and aluminum thermal shunts, similar to the current basket designs.

- Rectangular canisters designed to hold a few fuel assemblies: these canisters could have neutron absorber between assemblies and fit into a basket containing neutron absorber and aluminum thermal shunts.

- Large circular canister designed to hold multiple fuel assemblies and fit one per waste package: the canister would have an internal basket with neutron absorber, aluminum thermal shunts, and fuel tubes, similar to previous canistered fuel waste package designs.

E.2.1.8.1 *Potential Benefits*

Placing spent fuel assemblies in canisters before inserting them into waste packages would provide an additional barrier and limit mobilization of radionuclides in breached waste packages.

E.2.1.8.2 *Potential Environmental Considerations*

Use of this feature could cause an increase in the size of the Waste Handling Building and require additional workers. There would be an increase in operations and a possible increase in the number of lifts required per fuel assembly. This increase could be as much as one extra lift per assembly (canister), due to the moving of the canister to the waste package, which would lead to the potential for greater exposure to radiation for workers.

Implementation of this feature could increase the amount of rejected materials due to faulty welding, potentially generating more low-level radioactive waste and/or solid waste.

E.2.1.9 Additives and Fillers

Additives and fillers are materials that could be placed into waste packages (in addition to those normally required for the basket material) to fill the basket and waste form void spaces. The additives and fillers would:

- Sorb radionuclides and retard their release from a breached waste package
- Sorb boron neutron absorber that might be released from corrosion of the borated stainless steel absorber plates
- Displace moderator from the interior of the waste package to provide additional defense-in-depth for nuclear criticality control

Potential additives and fillers would be oxides of iron and aluminum. These materials could be placed within the waste package as a powder or as shot following loading of the waste form, or integrated into the basket design.

E.2.1.9.1 *Potential Benefits*

Additives and fillers could improve long-term repository performance by retardation of release of radionuclides to the groundwater and could also improve long-term criticality control.

E.2.1.9.2 *Potential Environmental Considerations*

Adding additives and fillers would make it more difficult to remove spent nuclear fuel assemblies from waste packages following retrieval, if necessary. Operations would have to include the additional step of removing this material before removal of the fuel.

E.2.1.10 Ground Support Options

Ground support in the repository ensures drift stability before closure. Selection of ground support options could affect repository waste isolation performance. Considerations of ground support options include functional requirements for ground support, the use of either concrete or steel-lined systems, and the feasibility of using an unlined drift ground support system with grouted rock bolts.

A concrete lining has been studied for its structural/mechanical behavior and subjected to the load conditions expected of emplacement drifts. However, a number of postclosure performance assessment issues related to the presence of concrete within the emplacement drift environment have been identified.

An all-steel ground support system (for example, steel sets with partial or full steel lagging) has been considered to be a viable ground support candidate for emplacement drifts. Use of an all-steel lining system would provide a means of limiting or eliminating the introduction of cementitious materials (that is, concrete, shotcrete, or grout), including organic compounds into the emplacement drift environment. The potential for corrosion of steel subjected to the emplacement drift environment is a concern with this system. Another concern is the interaction of steel ground supports with waste package materials.

For an unlined drift scenario, rockbolts and mesh could be considered as permanently maintainable ground support. Design and performance advantages associated with the use of rockbolts as permanent ground support for emplacement drifts include durability and longevity of this system. A postclosure concern would be the suitability of cementitious grout, which would be used for installing rockbolts.

E.2.1.10.1 *Potential Benefits*

Safety during emplacement and potential retrieval would be enhanced by use of appropriate ground supports. Long-term repository performance could be improved by reducing or delaying damage to canisters from rockfall, because damaged areas would be locations for enhanced corrosion even if the canister was not breached by the rockfall.

E.2.1.10.2 *Potential Environmental Considerations*

The choice of ground support options does not significantly impact any environmental consideration except for long-term repository waste isolation performance.

E.2.2 REPOSITORY DESIGNS TO CONTROL HEAT AND MOISTURE

E.2.2.1 Design Alternative 1, Tailored Waste Package Spatial Distribution

Tailored spatial distributions of waste packages within the repository block emplacement drifts could improve the postclosure waste isolation performance of the repository. The EIS design assumes the various waste package types would be emplaced on a random basis, modified only to meet the areal mass loading requirement of 25 to 85 MTHM per acre and the commercial fuel cladding and drift wall thermal goals of 350°C and 200°C (662°F and 392°F), respectively. There are three different methods of spatial distribution under review, including:

- Distribution of waste packages as a function of infiltrating water percolation rate within various regions of the repository block. Higher heat-producing packages would be placed in areas with higher percolation rates.
- Distribution of commercial spent nuclear fuel waste package types as a function of the distance to the water table and/or unsaturated zone zeolite content. Waste packages with radionuclides with the highest tendency to travel would be placed furthest from the water table, and waste packages with radionuclides with a higher tendency to be sorbed would be placed above areas with the highest zeolite content.
- Grouping waste package types into categories of hot, medium, and cold waste packages to even out the temperature differences across the repository.

E.2.2.1.1 *Potential Benefits*

Tailoring spatial distribution of the waste packages within the repository block might improve the performance of waste packages by delaying and reducing contact of water and/or increasing sorption of released radionuclides by zeolites in the unsaturated zone. This form of distribution has the potential to improve repository waste isolation performance.

E.2.2.1.2 *Potential Environmental Considerations*

Larger surface storage facilities could be needed to allow appropriate selection of waste packages for the desired spatial distribution. However, if the retrieval pad can be used for this purpose, no additional land would be needed.

E.2.2.2 Design Alternative 2, Low Thermal Load

The low thermal load design alternative would limit the temperature of the drift wall and host rock. It would cause less thermal change in the host rock than the Viability Assessment reference design. Limiting temperature rise would also reduce the uncertainty in predicting several processes, and thermal, chemical, mechanical, and hydrological effects would be easier to describe because coupling of these effects would extend over a smaller region than the Viability Assessment reference design. In this evaluation, a low thermal load refers to 40 MTHM per acre.

- *Option 1.* The waste package spacing would be the same as the spacing of the drifts, creating a square area between waste packages. The spacing of waste packages would be farther apart than in the Viability Assessment reference design. This option is the equivalent of the low thermal load implementing alternative analyzed in the EIS.

- *Option 2.* The spacing of the waste packages within the drifts would be 9 meters (30 feet) as in the Viability Assessment reference design, but drift spacing is increased to about 90 meters (300 feet). This can be compared to 28 meters (92 feet) for the Viability Assessment reference design.

- *Option 3.* This option consists of a greater number of smaller waste packages than in Option 1 or 2, and spacing of waste packages within the drifts is similar to Option 2. Drift spacing and excavated rock volume are about the same as for Option 1.

E.2.2.2.1 *Potential Benefits*

The primary benefit would be the reduction in uncertainties associated with higher thermal loads and the elevated temperature of the host rock. Lower repository temperatures could also potentially reduce waste package material corrosion rates.

E.2.2.2.2 *Potential Environmental Considerations*

Options 1 and 3 would result in generation of more excavated rock compared to the Viability Assessment reference design, and therefore requires a larger area for storage/disposal of excavated rock. Subsurface costs would increase. Option 2 would result in less volume of excavated rock than Option 1 or 3.

E.2.2.3 Design Alternative 3, Continuous Postclosure Ventilation

Under this alternative there would be continuous ventilation of the emplacement drifts during the postclosure period. Ventilation would occur by natural ventilation pressure induced by the difference in air density between hot and cool areas. Three primary options were considered:

- Closed loop airways connected underground but sealed to the surface

- Open loop airways where the primary airways stay open and in which the repository drifts are open to exchange air with the atmosphere; two additional ventilation shafts would be needed

- Open/closed loop ventilation where primary airways would be sealed, but drifts would be located very close to a system of tunnels open to the atmosphere

E.2.2.3.1 *Potential Benefits*

Postclosure ventilation would increase the removal of moisture from air around the waste packages for a period of time (estimated to be 1,000 to 2,000 years for the closed loop system), but moisture would eventually reestablish itself. Reduced moisture could improve performance by retarding waste package corrosion.

E.2.2.3.2 *Potential Environmental Considerations*

Excavated rock piles would increase in size in proportion to the increase in drift excavation required. Additional shafts would result in additional surface disturbed areas (small, relative to the Viability Assessment reference design). Additional occupational exposure to radon-222 associated with excavation would occur.

Overall, work force would increase by less than 10 percent, as would associated impacts such as industrial accidents.

E.2.2.4 Design Alternative 6, Viability Assessment Reference Design

The Viability Assessment reference design is equivalent to the high thermal load alternative evaluated in the EIS.

E.2.2.5 Design Alternative 7, Viability Assessment Reference Design with Options

The Viability Assessment reference design with options was considered as a design alternative in the License Application Design Selection Process. The Viability Assessment reference and design is analyzed in detail in the EIS. Options considered include ceramic coatings, drip shields, and backfill (see Sections E.2.1.1, E.2.1.2, and E.2.1.3, respectively).

E.2.2.6 Aging and Blending of Waste

Pre-emplacement aging and blending of wastes provides mechanisms for managing the thermal output of a waste package and the total thermal energy that must be accommodated by the repository.

Aging the waste before emplacement results in less variable (over time) thermal output of the waste packages and lower waste package temperatures. Aging could be performed at the repository, at the reactor sites, or at other locations.

Blending would allow a more uniform heat output from the waste packages. Blending would be accomplished by selecting waste forms for insertion in waste packages based on their heat output to minimize the variability in the thermal energy of each waste package.

E.2.2.6.1 *Potential Benefits*

Aging would reduce the temperature increase expected at the surface above the repository because the total heat load of the repository would be decreased. Lower heat output could also result in a smaller repository footprint by allowing more dense waste emplacement schemes without violating waste package or drift wall temperature goals. Both blending and aging reduce the variability of the temperature distribution in the repository, and drifts might be spaced more closely. Lower and equalized temperatures could improve structural stability of the drifts. Aging and blending would improve waste package stability (reducing rockfall-induced damage and corrosion) and improve long-term repository performance.

E.2.2.6.2 *Potential Environmental Considerations*

The blending feature might require a significantly larger storage pool size. This would increase the size of the pool storage building, and result in correspondingly higher costs. The Viability Assessment reference design staging pools have the capacity for about 300 MTHM. This would be reconfigured and expanded to allow for storage of up to 6,500 MTHM. Expanded pool storage would require additional resources (steel, concrete, gravel and asphalt, fuel, electricity and water for construction and operation, but the increases would not be significant (about 10 percent). Waste generation would also increase. During operations, use of well water will increase by about 15 percent. Well water is used to replace evaporative losses in the pools. Land use does not increase. Increases in worker population mean an increase in the potential for industrial accidents. Cumulative annual dose to workers would increase slightly, but the average dose to workers would not increase.

If aging is done at the Yucca Mountain site, a surface storage facility would be required. The effects of the aging feature are identical to the retrieval contingency discussed in the EIS because the same size storage facility/pad would be needed. The retrieval contingency assumes a surface storage facility able to handle the entire repository inventory.

E.2.2.7 Continuous Preclosure Ventilation

Continuous preclosure ventilation would provide increased air flow in the emplacement drifts compared to the reference design preclosure ventilation rate of 0.1 cubic meter (3.5 cubic feet) per second. The system would be shut off at closure.

Additional excavation would be required for an additional exhaust main. The actual number of emplacement drifts would not change, but the layout of drifts would vary slightly to accommodate the additional ventilation shafts. The sizes of the shafts would have to be increased and more would need to be added. Access drifts and additional connections would have to be added between the exhaust mains and the shafts.

E.2.2.7.1 *Potential Benefits*

Continuous ventilation in the preclosure period could reduce the rock wall and air temperature. It could also remove enough moisture to reduce the length of time the waste packages are exposed to temperature/ moisture conditions that could result in higher corrosion rates. The removal of moisture also would increase the stability of the ground-support system. In addition, with lower drift temperatures retrieval would be easier.

E.2.2.7.2 *Potential Environmental Considerations*

Additional drifts and intake and exhaust shafts would be required to handle the additional airflow quantities, resulting in additional excavated rock. Additional shaft locations would disturb land surface in the limited locations available to place the` shafts, and roads would have to be constructed to the shaft sites. Additional shafts and night lighting at the top of the mountain might be visible from off the Yucca Mountain site.

The changes in repository ventilation would increase emissions of naturally occurring radon-222 and its radioactive decay products in the air exhausted from the subsurface. Power requirements could increase substantially during emplacement operations and postclosure monitoring.

The number of workers would increase by less than 10 percent, with an attendant increase in the potential for industrial accidents.

Closure would be more difficult because there would be additional openings to seal.

E.2.2.8 Drift Diameter

The emplacement drift diameter is a secondary design feature because the diameter is determined by a number of primary design features. The size of the emplacement drift could directly affect design considerations such as opening stability (rockfall potential), the extent of the mechanically induced disturbed zone, and the amount and location of seepage into the drifts.

The drift diameter for the Viability Assessment reference design is 5.5 meters (18 feet). A range of drift diameters is being considered [from 3.5 meters (11 feet) to 7.5 meters (25 feet)].

E.2.2.8.1 *Potential Benefits*

A smaller diameter drift is inherently more stable and could reduce the need for ground-support systems, potentially reducing costs. The smaller drift diameter would also be less susceptible to water seepage. A larger diameter allows for other modes of emplacement, such as horizontal or vertical borehole emplacement. Both of these emplacement modes would reduce the potential for damage to waste packages from rockfall, therefore potentially improving long-term performance of the repository.

E.2.2.8.2 *Potential Environmental Considerations*

An increase in drift diameter could increase the potential for rockfall (both size and frequency) and decrease the overall opening stability. Rockfall could breach waste packages or cause lesser damage to the packages, providing locations for accelerated corrosion. Also, the larger the drift diameter, the more vulnerable it would be to water entry from seepage flow.

A smaller drift diameter would be inherently more stable in highly jointed rock and a decreased rockfall size would be anticipated. A change to a smaller diameter could allow modification to the ground-support system with possible elimination of a full circle drift liner. Although a smaller drift diameter would be less susceptible to seepage, the smaller diameter drift might result in short-term increases of temperature, which could affect the characteristics of potential groundwater movement.

Increasing the emplacement drift diameter would result in an increase in the quantity of excavated rock and increased use of equipment and materials, higher releases of radon-222, and lower ventilation air velocity. The lower air velocity would result in greater quantities of radon–222 and dust during development, an important consideration for preventing suspension of respirable silica dust.

A smaller drift diameter, although reducing the potential of radon-222 releases, might not be able to provide the quantities of air necessary for ventilation without raising velocities to undesirable levels. Increased drift diameter would require more workers for tunnel boring machine operations, excavated rock handling, ground-support installation and finishing works, surface equipment operators, and maintenance. A decrease in the drift diameter would have an opposite affect on the worker requirements;

that is, with a larger drift diameter, the additional excavation work would produce an increase in worker accidents. Larger tunnel boring machines could require substantially more electrical power.

E.2.2.9 Drift Spacing and Waste Package Spacing

In repository design, thermal load refers to a density at which the waste packages will be emplaced in the repository. The Viability Assessment reference design involves emplacement of waste packages in drifts in a horizontal mode, and thermal load is directly related to the emplacement drift and waste package spacing. The Viability Assessment reference design used a spacing of 28 meters (92 feet) between drifts.

For a given drift spacing, emplacement of waste packages can be arranged by using point load (waste package spacing determined based on individual waste package characteristics, such as mass content or equivalent heat output of each waste package), or line load [waste packages are emplaced nearly end to end that is, with a 0.1-meter (0.3-foot) gap with no considerations of individual waste package characteristics].

The point load approach was used for the Viability Assessment reference design. Waste-package spacing was determined based on mass content of waste packages, to achieve an overall area mass loading of 85 MTHM per acre for commercial spent nuclear fuel.

The line load method would be expected to provide a more intense and uniform heat source along the length of emplacement. An increase in emplacement drift spacing would be required in conjunction with line loading to maintain a constant overall thermal loading density (for example, 85 MTHM per acre).

E.2.2.9.1 *Potential Benefits*

The line load approach would keep the emplacement drifts hot and dry longer and would decrease the amount of water that could contact waste packages. Consequently, waste package performance could be improved. The line load approach would also reduce the number of emplacement drifts needed for waste emplacement. However, the concentrated heat load in the drifts could require continuous ventilation of emplacement drifts to meet the near-field temperature requirements. Continuous ventilation is discussed in Section E.2.2.7.

E.2.2.9.2 *Potential Environmental Considerations*

Line loading would require excavation of about 30 fewer emplacement drifts, with correspondingly less excavated rock, dust, and pollutants from diesel- and gasoline-powered equipment and vehicles. Decreased excavation would also reduce radon-222 release in the underground facility. However, decreasing the waste package spacing would result in potentially large increases in the rock temperatures in and near the emplacement drifts. This could create the need for continuous ventilation of emplacement drifts, which could increase emissions of naturally occurring radon-222 and its radioactive decay products in the air exhausted from the subsurface.

The reduction in total work and material requirements would be expected to be linearly proportional to the reduction in required drift length. Fewer work hours would also result in less potential for industrial accidents during construction. Decreased emplacement drift excavation would reduce the demand for electric power, equipment fuel, construction materials, and site services. However, the higher drift temperature associated with the line load option could require continuous ventilation of emplacement drifts.

E.2.2.10 Near-Field Rock Treatment

Near-field rock treatment involves injection of a grout material into the cracks in a portion of the rock above each emplacement drift to reduce the hydraulic conductivity of the treated rock. Injection would start at least 6 meters (20 feet) above the drift crown and would form a zone at least 4 meters (13 feet) thick, extending at least 6 meters on each side of the drift. Injection would be through holes 2.5 to 5 centimeters (1 to 2 inches) in diameter drilled from inside each drift prior to waste emplacement. Injection pressures would not exceed a certain minimum pressure, selected to limit rock fracturing or joint opening.

The candidate materials include Portland cement grout, sodium silicate, bentonite (a clay), and calcite.

E.2.2.10.1 *Potential Benefits*

Reducing the hydraulic conductivity of the rock would improve long-term repository performance by reducing or retarding postclosure water seepage into the drifts.

E.2.2.10.2 *Potential Environmental Considerations*

Installation of the grout material would require additional labor hours, with an associated change in the potential for industrial accidents.

E.2.2.11 Surface Modification – Alluvium Addition

Covering the surface of Yucca Mountain above the repository footprint with alluvium could decrease the net infiltration of precipitation water into the repository by increasing evapotranspiration. To cover the mountain with alluvium, the surface of the mountain would be modified to prevent the alluvium from washing away. Ridge tops on the eastern flank of Yucca Mountain would be removed and the excavated rock placed in Solitario Canyon and in Midway Valley or used to fill the alluvium borrow pit. The maximum slope of the ground surface remaining would be approximately 10 percent. Alluvium [approximately 2 meters (7 feet) thick] would be placed on the new surface and vegetation would be established. New haul roads to move the necessary materials would have to be constructed.

E.2.2.11.1 *Potential Benefits*

Reduced net infiltration would improve long-term repository performance. However, there is uncertainty about the permanence of both the vegetation and the alluvium that would be added to the surface of Yucca Mountain.

E.2.2.11.2 *Potential Environmental Considerations*

Approximately 8 square kilometers (2,000 acres) on Yucca Mountain would be resloped and covered. The excavated material would cover 4.8 square kilometers (1,200 acres) in the fill area in Solitario Canyon. The borrow pit would be about 5.2 square miles (1,300 acres). Additional access roads would also be needed. Yucca Crest would be lower by approximately 30 to 60 meters (98 to 197 feet) the ridges on the east side of Yucca Crest would be lowered by as much as 80 meters (262 feet). Quantities of material to be moved would include:

- Total rock cut from Yucca Mountain 220 million cubic meters (17,600 acre-feet)
- Total alluvium removed from the alluvium borrow pit (probably in Midway Valley) about 22 million cubic meters (17,600 acre-feet)

The operation would be equivalent to a major, large-scale open pit mining operation. It would likely require a labor force of about 75 people per shift. There would be an increase in the potential for industrial accidents because of the additional work. Generation of particulate emissions (fugitive dust) and gaseous criteria pollutant emissions from vehicles would increase.

There would be alterations to natural drainage; however, the potential for flooding would not increase with proper design.

The view to and from Yucca Mountain would be altered. Mining operations at the top of the mountain would be visible for some distance, and the mountain would be considerably lower. Vegetation would be restored because the design requires vegetation as part of the evapotranspiration process. The operation would be carried out on three shifts, and night lighting on the top of the mountain could be visible to the public.

E.2.2.12 Surface Modification – Drainage

Surface modification could reduce infiltration at the surface of the mountain. Net infiltration into Yucca Mountain could be significantly decreased if the thin alluvium layer over the footprint of the repository were removed to promote rapid runoff of the surface water. It has been shown that where the alluvium is thin, it retains the surface water and allows it to infiltrate into the unsaturated zone. Where bedrock is exposed on slopes, the water runs off rapidly and net infiltration is very small or reduced to zero.

The thin alluvium layer would be stripped from the topographic surface above the repository footprint and a 300-meter (984-foot) buffer surrounding it.

E.2.2.12.1 *Potential Benefits*

Reduced infiltration would result in improved long-term repository waste isolation. However, there is uncertainty about the permanence of alluvium removal. In addition, while infiltration might be reduced on the top of the mountain, infiltration could increase in other areas because of the higher volumes of surface water runoff.

E.2.2.12.2 *Potential Environmental Considerations*

The amount of land modified to improve drainage would be approximately 1,100 acres, located mainly on the eastern flank of Yucca Mountain. Additional road construction would also be required. The removed alluvium, about 2.1 million cubic meters (2.7 million cubic yards), would be placed in Midway Valley. There would be alterations to natural drainage, and the increased runoff could increase the potential for flooding. The landforms would be changed only slightly because of the thin [less than 0.5-meter (1.6-foot) thick] alluvium that would be removed. Any existing vegetation on the side of the ridges would be removed during the process of alluvium removal. Bare bedrock would be exposed, which would discourage vegetation from growing except from cracks in the rock.

Additional workers would be required, and there would be an accompanying increase in the potential for industrial accidents.

Night lighting would be needed to support this operation that could be visible from off the site.

E.2.2.13 Higher Thermal Loading

Higher thermal loading would keep the drift temperature above the boiling point longer, thereby minimizing the amount of moisture around the waste package during a longer postclosure period. The higher thermal loading could also have adverse effects on the surrounding rock. This feature could also be combined with aging to achieve greater mass loading per acre of repository area.

Higher thermal loads could be achieved by either decreasing drift spacing, by placing waste packages closer together in the drift, or by a combination of drift spacing and waste package spacing. In all three cases, the increased number of waste packages in a given area would result in a higher thermal load to a given area of the repository.

The benefits and environmental considerations associated with this feature would be similar to those discussed under Drift Spacing and Waste Package Spacing (Section E.2.2.9).

E.2.3 REPOSITORY DESIGNS TO SUPPORT OPERATIONAL AND/OR COST CONSIDERATIONS

E.2.3.1 Design Alternative 4, Enhanced Access

The purpose of the enhanced access design would be to provide additional shielding around the waste package to allow for personnel accessibility during waste package loading, transfer to the drift, emplacement, and performance confirmation. Shielding would lower the dose rate to less than 25 millirem per hour. Enhanced access could be provided by:

- Additional shielding integral to the waste package
- Supplemental (separate from the waste package) shielding in the emplacement drifts only
- Portable shielding for personnel to access the drift

E.2.3.1.1 *Potential Benefits*

The major benefit of these three options would be to provide access to the emplacement drifts so personnel could carry out performance confirmation activities. Enhanced access designs could also offer increased access for maintenance and ease of operations, and the potential elimination of some remote handling equipment. If shielding were left in place at closure, it could provide additional protection for waste packages from rock falls.

E.2.3.1.2 *Potential Environmental Considerations*

Increased personnel access would increase occupational exposure, even with the additional shielding. Enhanced access would decrease the number of observation and performance confirmation drifts needed, and slightly decrease the volume of excavated rock piles.

The addition of shielding to waste packages would result in increased materials usage. Shielding materials could be steel, concrete, magnetite concrete (concrete with iron shot included), or Ducrete® (concrete with depleted uranium included).

E.2.3.2 Design Alternative 5, Modified Waste Emplacement Mode

In a modified waste emplacement design, unshielded waste packages would be emplaced in a configuration in which the repository's natural or engineered barriers would provide shielding. Examples include placing waste packages in boreholes drilled into the floor or wall of emplacement drifts, in alcoves off the emplacement drifts, in trenches at the bottom of the emplacement drifts, or in short cross drifts excavated between pairs of excavated drifts. In each case, some type of cover plug would be used to shield radiation in the emplacement drifts.

Unshielded waste packages, which in some designs would have a smaller capacity than specified in the Viability Assessment reference design, would be used.

E.2.3.2.1 *Potential Benefits*

Natural or engineered barriers would enhance human access, reduce performance confirmation costs, and facilitate conducting inspections and maintaining ground support. Retrieval operations would also be easier because of easier access.

E.2.3.2.2 *Potential Environmental Considerations*

The footprint of the repository would not change, but the amount of excavated rock would increase. The vertical borehole emplacement concept would generate the most additional excavated rock. Peak power consumption would increase substantially because of the use of additional boring machines.

E.2.3.3 Design Alternative 8, Modular Design (Phased Construction)

Modular design is an alternative that could reduce annual expenditures during construction if annual funding is constrained below that required for the Viability Assessment reference design. This alternative would include staged modular construction of repository surface and subsurface facilities.

The modularized Waste Handling Building would be designed to handle specific types of waste forms and quantities. The modular concept would include one Waste Handling Building completed in modular phases or two separate buildings constructed in sequence.

E.2.3.3.1 *Potential Benefits*

The primary benefit would be leveled cash flow during construction.

E.2.3.3.2 *Potential Environmental Considerations*

The dual buildings would increase the overall size of the Waste Handling Building by an estimated 10 percent. The Radiologically Controlled Area could increase by about 10 percent or less. Operating times (years of operation) would be extended and operations would be at a lower rate.

Some options would involve receipt of spent nuclear fuel from reactor sites prior to the start of emplacement that could increase worker dose because it would have to be handled twice.

E.2.3.4 Rod Consolidation

Both pressurized-water reactor and boiling-water reactor fuel assemblies have fuel rods arranged in regular square arrays with rod-to-rod separation maintained by the fuel assembly hardware. Rod consolidation would involve eliminating this separation and bringing the fuel rods into close contact. Reducing the volume taken up by fuel assemblies would allow the capacity of waste packages to be increased and/or the size of waste packages to be reduced. Consolidation could be done at either the current spent fuel storage locations or at the repository.

Rod consolidation would be accomplished by removing fuel rods from an assembly, repackaging the rods in a denser arrangement in a suitable canister, and loading the new canister into a waste container. This process could occur either in a pool or in a dry (hot cell) environment.

E.2.3.4.1 *Potential Benefits*

A reduced number or size of waste packages would be possible and could result in reduced emplacement costs. If rod consolidation took place at the reactor sites, waste transportation requirements might be reduced.

E.2.3.4.2 *Potential Environmental Considerations*

Because of the disassembly operations, the size of the Waste Handling Building would more than double in area if rod consolidation were done at the repository. With the large number of fuel rod handling operations in the hot cells, there would be a greater potential for radiological releases due to fuel handling accidents (such as dropping a fuel rod/assembly).

The number of workers at the repository could increase if rod consolidation were performed at the repository. With an increase in the number of fuel handling operations, the number of fuel handling accidents would increase and result in a small increase in radiological exposure for onsite workers.

Approximately 10 to 40 kilograms (22 to 88 pounds) of leftover, nonfuel components from each as-received fuel assembly would be packaged as Class C or Greater-Than-Class-C low-level wastes. In addition, low-level waste would be generated by decontamination and disposal of equipment. Low-level waste would be transported to the Nevada Test Site or other appropriate facility for disposal. Greater-than-Class-C wastes could be disposed of offsite or in the repository with approval of the U.S. Nuclear Regulatory Commission.

Waste packages containing consolidated fuel rods might result in higher cladding temperatures, which could damage the cladding and have negative impacts on waste isolation performance.

E.2.3.5 Timing of Repository Closure

The first option assumes that the subsurface facilities would be fully maintained to the same level of readiness during the 300-year period as planned for the 100-year period assumed for the Viability Assessment reference design. There would be continuous ventilation during the entire 300-year period. The second option assumes the Nuclear Regulatory Commission would have approved completion of the Performance Confirmation Program at the end of the first 100 years, and that continued access to the emplacement drifts would no longer be required. The second option considers that ventilation, maintenance, and repairs would be reduced to a minimum for cost considerations, but that temperatures would be maintained at 50°C (122°F) or less for human access to the subsurface (nonemplacement) facilities.

E.2.3.5.1 *Potential Benefits*

Extending the period before final closure would allow for reduction of waste package heat output, extended monitoring, and extended retrieval period for the waste.

E.2.3.5.2 *Potential Environmental Considerations*

Delayed closure of the repository would lengthen the time that land would remain disturbed through the occupation of surface facilities necessary to support extended operations from 100 to 300 years. It would delay the reclamation of surface stockpiles retained for filling the mains, ramps, and shafts.

The release of radon-222 from excavations is proportional to time. Delayed closure from 100 to 300 years would increase the emissions of radon-222 by a factor of approximately 3.6.

The number of workers required for monitoring would not change. However, the number of labor hours required, compared to the Viability Assessment reference design monitoring period, would be 3.6 times the number required for closure at 100 years. The base case scenario requires the periodic retrieval of waste packages for performance confirmation testing. An increase in the monitoring period from 76 to 276 years would increase radiation exposure due to increased waste package handling. More frequent inspections would be likely during this extended period due to aging. Additionally, emplacement drifts maintenance would require removal and re-emplacement of waste packages. An increased monitoring period would increase the potential for industrial accidents and radiological exposure.

E.2.3.6 Maintenance of Underground Features and Ground Support

A maintenance program in the emplacement drifts would be needed to accommodate an extended long-term repository service life and to reduce the risk of keeping the repository open for an additional 200 years. Repository emplacement drift ground support components would have to be designed and maintained for a service life of greater than 300 years, including closure and retrieval times.

E.2.3.6.1 *Potential Benefits*

The benefits are the same as those listed in Section E.2.3.5.1

E.2.3.6.2 *Potential Environmental Considerations*

Some types of maintenance in the emplacement drifts would require retrieval of waste packages for maintenance access. Blast cooling would be needed to lower the temperature to below 50°C for worker access. There could be additional radiological exposure to workers.

E.2.3.7 Waste Package Self-Shielding

In the Viability Assessment reference design, handling of waste packages in the emplacement drifts would be performed remotely, and human access to the emplacement drifts would be precluded when waste packages are present. Waste package self-shielding would reduce the radiation in the drifts to levels such that personnel access would be possible. This would allow direct access to the performance confirmation instrumentation, and maintenance and repair in the drifts.

Self-shielding would be accomplished by adding a shielding material around the waste packages. Candidate materials include A516 carbon steel, concrete with depleted uranium (Ducrete®), magnetite concrete, and a composite material of boron-polyethylene and carbon steel.

The amount of shielding would depend on the target radiation dose level in the drift environment. For a 25-millirem-per-hour waste package contact dose, the estimated thickness of the concrete would be about 0.6 meter (2 feet). For higher contact doses, less shielding material would be required.

E.2.3.7.1 *Potential Benefits*

Monitoring, maintenance, and retrieval would be easier with contact handling of the waste packages.

E.2.3.7.2 *Potential Environmental Considerations*

Self-shielding could not be used with high thermal loading because the shielding would provide a thermal barrier that would result in excessive fuel cladding temperature. Smaller waste packages would maintain a constant outside diameter but would also require about four times as many waste packages and more drifts. Radon-222 emissions would increase in proportion to the additional excavation.

Concrete shielding would be applied at the repository, and the number of workers would slightly increase, as would the number of industrial accidents. There could be a reduction in radiological exposure to workers during emplacement operations. The concrete shielding could degrade the long-term performance of the waste packages.

E.2.3.8 Repository Horizon Elevation

This feature considers a two-level repository to increase repository capacity without moving out of the characterized area.

One two-level concept would divide the Viability Assessment reference design layout along a north-south axis and would relocate the western half above the eastern half. A second two-level concept would duplicate the Viability Assessment reference design layout 50 meters (164 feet) above the current footprint. The thermal loading of each level could be adjusted to increase the capacity.

E.2.3.8.1 *Potential Benefits*

There would be two potential advantages to repository long-term performance. Increased thermal load would potentially enhance the umbrella effect (this could reduce the amount of water that could come in contact with the waste package). There would also be added flexibility in emplacing waste packages on the lower level, which could be shielded from moisture infiltration by the upper level horizon.

Retrieval could be accomplished more quickly due to the ability to operate two independent retrieval operations at the same time.

E.2.3.8.2 *Potential Environmental Considerations*

The first two-level concept could use slightly less land area to store excavated rock because less material would be excavated. The second two-level concept could double the excavation and double the excavated rock volume that would require storage.

Surface soil temperatures could increase due to locating waste closer to the surface and/or increasing thermal loading per acre.

Construction of the full size footprint two-tier repository would require slightly less than double the number of workers and a longer construction period, with associated changes in the potential for industrial accidents. Power consumption would approximately double.

E.3 Enhanced Design Alternatives

Enhanced Design Alternatives are combinations of the alternatives and design features described in preceding sections. These concepts were developed to cover a range of potential repository designs as part of the License Application Design Selection Process described in Section E.1.2. Enhanced Design Alternatives are intended to be improvements to the basic design alternatives discussed in Section E.2. Five Enhanced Design Alternatives are described below, along with the design concepts that led to their development. Potential benefits and environmental considerations are discussed in the sections above dealing with the design alternative and design features incorporated into each Enhanced Design Alternative.

At the time of development of this appendix, the Enhanced Design Alternatives discussed below had been developed, but documentation of the Enhanced Design Alternative development process was forthcoming. That documentation was scheduled to be complete in May 1999. The Enhanced Design Alternatives described in the following sections are preliminary and based on observations of the License Application Design Selection Process and informal discussions with process participants.

E.3.1 ENHANCED DESIGN ALTERNATIVE I

Enhanced Design Alternative I is a low-temperature design intended to remove uncertainties and modeling difficulties associated with above-boiling temperatures. Lower temperatures would mean less disturbance of the subsurface and limit the combined effects of thermal, hydrological, and geochemical processes that are more pronounced in above-boiling-temperature environments.

The goals of Enhanced Design Alternative I are to keep the drift wall temperature below the boiling point of water and the commercial fuel cladding temperature below 350°C (662°F). This would be achieved for the Enhanced Design Alternative I design by limiting areal mass loading to 45 MTHM per acre, increasing the size of the repository to 6 square kilometers (1,500 acres), and using smaller waste packages. Drift spacing would be 43 meters (141 feet) between drift centerlines, with an average end-to-end waste package spacing of 3 meters (10 feet). Preclosure ventilation would use two intake and three exhaust shafts.

The waste package design for this Enhanced Design Alternative would consist of two layers, with Alloy-22 on the outside and 316L stainless steel (nuclear grade) on the inside. Flexible waste package spacing would be used to control the drift temperature. Blending would be used to reduce the maximum thermal output of a waste package to 6.7 kilowatts. To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. A 2-centimeter (0.8-inch)-thick titanium-7 drip shield, to be placed over the waste package just prior to closure, is included in this design to provide defense in depth.

This design allows human access using blast cooling and portable shielding [15 centimeters (6 inches) stainless steel and 7.5 centimeters (3 inches) borated polyethylene].

The major disadvantage of this design is that it uses all of the available space in the upper repository block. Another disadvantage is that it uses smaller waste packages, requiring about 6,000 more waste packages than other Enhanced Design Alternatives.

E.3.2 ENHANCED DESIGN ALTERNATIVE II

Enhanced Design Alternative II is a moderate temperature design intended to keep commercial fuel cladding temperature below 350°C (662°F) and to keep the boiling fronts from merging in the rock walls between the drifts. Keeping a non-boiling area between the drifts ensures that there would be sufficient area between the drifts that would be below the boiling point to allow water to drain. The areal mass loading could be up to 60 MTHM per acre and still achieve these goals.

The waste package design would consist of two layers with Alloy-22 on the outside and 316L stainless steel on the inside. Blending would be used to reduce the maximum heat output of a waste package to 9 kilowatts. The emplacement area would be 4.3 square kilometers (1,064 acres), and the waste package design would be the same as for Enhanced Design Alternative I. The Enhanced Design Alternative II design would use closely spaced waste packages, line loading, and a drift spacing of 81 meters (266 feet). To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. This design also includes backfill, a 2-centimeter (0.8-inch)-thick titanium-7 drip shield placed just prior to closure, as in Enhanced Design Alternative I. Continuous ventilation would be used for the 50-year preclosure period.

An advantage of this design is that it would reduce or avoid uncertainties associated with the thermal period or thermal pulse where large quantities of water could pool above the repository area. The cooler pillars between the drifts would allow for drainage of waters. However, an uncertainty is that the drainage of water has not been demonstrated. Another advantage is that the design provides flexibility for modification to either a hotter or cooler design.

E.3.3 ENHANCED DESIGN ALTERNATIVE III

Enhanced Design Alternative III is a high thermal load design. The goals are to keep the drift wall temperatures below 200°C (329°F), the commercial fuel cladding temperature below 350°C (662°F), and to ensure that the waste package surface temperature cools to below 80°C (176°F) before the relative humidity at the waste package surface rises above 90 percent. These goals would be met with an 85 MTHM per acre loading, close [0.1 meter, (0.3 foot)] spacing of line-loaded waste packages, and a drift spacing of 56 meters (184 feet).

Two different waste packages are considered (Enhanced Design Alternatives IIIa and IIIb). The Enhanced Design Alternative IIIa waste package would use a two-layer design with 2 centimeters (0.8-inch) of Alloy-22 over 5 centimeters (2 inches) of 316L stainless steel (as in Enhanced Design Alternatives I, II, and V). The Enhanced Design Alternative IIIb waste package design would use a waste package with an outer layer of 2.2 centimeters (0.9 inch) of Alloy-22 over 1.5 centimeter (0.6 inch) of titanium-7 that have been shrink-fitted together, and a 4-centimeter (1.6-inch) inner layer of 316L stainless steel that would fit loosely (gap of 4 millimeters or less) inside the Alloy-22/titanium-7 shell.

Blending would not be used in Enhanced Design Alternative III. However, preclosure ventilation of at least 5 cubic meters (177 cubic feet) per second would be needed for a minimum of 50 years to achieve the temperature goals of this Enhanced Design Alternative. This would require two intake and three exhaust shafts in addition to the access tunnels. Enhanced Design Alternative III also includes a titanium-7 drip shield.

The advantage of Enhanced Design Alternative III is that the surface of the waste package is predicted to cool below 80°C (176°F) before the relative humidity exceeds 90 percent, thus avoiding the worst of the corrosive, warm-moist environment after closure. The disadvantages are the uncertainties connected with temperatures over 100°C (212°F).

E.3.4 ENHANCED DESIGN ALTERNATIVE IV

Enhanced Design Alternative IV is a shielded waste package design located entirely in the upper block with a high thermal load (85 MTHM per acre). The goals of this Enhanced Design Alternative are to keep the gamma radiation dose at the surface of the waste package below 200 millirem per hour, keep the fuel cladding below 350°C (662°F), and keep the emplacement drifts dry for thousands of years.

The waste package would be 30-centimeter (12-inch)-thick A516 steel, and it would have an integral filler that acted as a sponge for oxygen. Waste packages would be line-loaded with a separation of 0.1 meter (0.3 feet). Continuous ventilation at 2 to 5 cubic meters (71 to 177 cubic feet) per second would be required for the 50-year preclosure period. Two intake and three exhaust shafts would be required in addition to the access tunnels. Human access would require blast cooling to reduce temperatures in the drift using a portable 5-centimeter (2-inch)-thick borated polyethylene neutron shielding over the waste packages. Backfill material and drip shields are used in this Enhanced Design Alternative.

The Enhanced Design Alternative IV waste packages would weigh 18,140 metric tons (20 tons) more than those used with other Enhanced Design Alternatives. Since this Enhanced Design Alternative requires a hot postclosure environment to be successful, it would be necessary to manage the waste stream to ensure uniform heat in the repository. Backfill would be placed at closure.

If this design concept does not properly control temperature and relative humidity to protect the drip shield, the carbon steel waste packages would be expected to fail much earlier than the waste packages in the other Enhanced Design Alternatives.

E.3.5 ENHANCED DESIGN ALTERNATIVE V

Enhanced Design Alternative V is a very high thermal load alternative (150 MTHM per acre) and covers the smallest area [168 square kilometers (420 acres)] of the five Enhanced Design Alternatives. The purpose of the very high thermal load is to provide a hot, dry drift environment for thousands of years and avoid extended periods of warm, moist conditions. The goals of this Enhanced Design Alternative were to have drift wall temperatures less than 225°C (437°F) to maintain stability, commercial fuel cladding temperature less than 350°C, and to keep the drift dry for several thousand years.

Waste blending would be required so that waste temperatures were all within 20 percent of the average. Waste packages would be 2-centimeter (0.8-inch) Alloy-22 over 5-centimeter (2-inch) 316L stainless steel, and they would be line loaded with a 0.1-meter (0.3-foot) spacing between waste packages. To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. Drift spacing would be 32.4 meters (106 feet). Preclosure ventilation would reduce air and drift temperatures and remove moisture from the drifts. Four air shafts as well as three access tunnels would be needed. Titanium-7 drip shields would be placed at the time of closure.

The advantage of this design is that it would be located entirely in the lower block of the repository, where the percolation rate is less than half that in the upper block. However, access to the lower block would require a third tunnel. In addition, postclosure conditions could lead to localized corrosion and early failure of waste packages. The high temperatures also could create the possibility that the cladding temperature goal would be exceeded for some waste packages.

REFERENCE

DOE 1998 — DOE (U.S. Department of Energy), 1998, *Viability Assessment of a Repository at Yucca Mountain*, DOE/RW-0508, Office of Civilian Radioactive Waste Management, Washington, D.C. [U.S. Government Printing Office, MOL.19981007.0027, Overview; MOL.19981007.0028, Volume 1; MOL.19981007.0029, Volume 2; MOL.19981007.0030, Volume 3; MOL.19981007.0031, Volume 4; MOL.19981007.0032, Volume 5]