Appendix E

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 PURPOSE

The purpose of this appendix is to give the reader a perspective on the development of the conceptual design used for environmental impact analysis of the proposed Yucca Mountain Repository in this Final Environmental Impact Statement (EIS). The basic design concept of packaging spent nuclear fuel and high-level radioactive waste in corrosion-resistant, long-life containers for emplacement in drifts drilled into the unsaturated rock structure of Yucca Mountain has not changed from the design evaluated in the Draft EIS. The flexible design evaluated in this Final EIS does, however, include a number of features and alternatives that were not part of the Draft EIS design. The U.S. Department of Energy, (DOE or the Department) added these features and alternatives to the design primarily to increase operational flexibility, enhance long-term performance, and reduce long-term uncertainty. DOE presented the flexible design and evaluated its environmental impacts in the Supplement to the Draft EIS.

E.1.2 BACKGROUND

E.1.2.1 General Background

The preliminary conceptual design used for environmental analysis in the Draft EIS was described in the *Viability Assessment of a Repository at Yucca Mountain* (DIRS 101779-DOE 1998, all), and was referred to as the Viability Assessment reference design. The Viability Assessment concluded that "uncertainties remain about key natural processes, the preliminary conceptual design and how the site and the design would interact" (DIRS 101779-DOE 1998, Overview, p. 2). Recognizing that the design would continue to develop, the Viability Assessment noted that "DOE is evaluating several design options and alternatives that could reduce existing uncertainty and improve the performance of the repository system" (DIRS 101779-DOE 1998, Overview, p. 30). DOE evaluated the design options in the License Application Design Selection project.

E.1.2.2 Background on the License Application Design Selection Project

Phase I of the License Application Design Selection project involved identifying and analyzing a set of design features and design alternatives that had potential value as elements in the repository design. Phase I was underway as the Draft EIS was being prepared. Accordingly, Appendix E of the Draft EIS contained a list of the design features and alternatives that had been developed to that point in time along with some very preliminary discussion of potential benefits and potential environmental impacts. Phase II of the License Application Design Selection project involved developing a set of enhanced design alternatives from combinations of the design alternatives and features prepared in Phase I. The following definitions of design features, design alternatives, and enhanced design alternatives, provide insight into how the process worked.

- Design alternative—Each design alternative represents a fundamentally different conceptual design for the repository and could stand alone as the License Application repository design concept. Design alternatives are distinguished from design features by their complexity and the number of attributes involved. Design alternatives, while not mutually exclusive, represent diverse and independent methods of accomplishing the repository mission—safe disposal of spent nuclear fuel and high-level radioactive waste. One example of a design alternative is a repository designed to use continuous natural ventilation to remove heat and moisture from the area of the waste packages after the repository has been closed.

- Design feature—A design feature is a particular element or attribute of the repository that could be added to a design alternative to enhance its performance. An individual design feature can represent a discrete concept, such as use of shielded waste packages, or a continuous range of values of some aspect of repository design, such as spacing of the waste emplacement drifts. Design features can be added to any design alternative singly or in combination, although the compatibility of different design alternatives and design features varies.

- Enhanced design alternative—Enhanced design alternatives are combinations of one or more design alternatives and design features that fit logical principles derived from the objectives for repository design. Enhanced design alternatives selected for evaluation are those combinations that include mutually compatible attributes and expected postclosure performance characteristics that exceed those of the basic design alternatives. Other characteristics considered in developing enhanced design alternatives include the compatibility of the design alternatives and design features; 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 alternatives and design features.

The final *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all) recommended, and DOE subsequently chose, a particular combination of design alternatives and features called Enhanced Design Alternative II to carry forward in the design evolution. However, DOE did specify that backfill should be only a possible option in Enhanced Design Alternative II. Accordingly, DOE adopted Enhanced Design Alternative II without backfill as the design for continued development.

E.1.2.3 Background on the Science and Engineering Report

The current repository conceptual design, which is based on Enhanced Design Alternative II without backfill, is discussed in the *Yucca Mountain Science and Engineering Report: Technical Information Supporting Site Recommendation Consideration* (DIRS 153849-DOE 2001). This report was the basis for the Supplement to the Draft EIS and remains the basis for this Final EIS.

The flexible design described in the Science and Engineering Report and in the Supplement to the Draft EIS uses more extensive thermal management techniques to limit the heat released by the waste than the design evaluated in the Draft EIS. In addition to the design enhancements that would result directly from the proposed features and design alternatives discussed below, this design would be the most flexible in terms of accommodating other higher- or lower-temperature operating conditions.

The following sections identify and describe the design features and alternatives that DOE has considered in the design evolution of the repository. Some of the features and alternatives discussed in the following paragraphs have been incorporated in the current design. Most, while no longer being actively considered, have not been eliminated entirely. DOE expects the design to continue to evolve through the licensing process, so additional limited development and enhancement could occur as the design matures. The features and alternatives described below provide a framework for the design evolution that has occurred to date, and any future design evolution, along with a qualitative evaluation of environmental impacts.

E.1.3 SUMMARY OF DESIGN ALTERNATIVES AND FEATURES

The design alternatives and features considered in the development of the flexible design analyzed in the Final EIS are listed in Tables E-1 and E-2. The design alternatives and design features listed in Tables E-1 and E-2, respectively, are listed in the same order and with the same title as in the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). Design features 21 and 22, Dry Handling and Site Access Road, respectively, were not included in the License Application Design Selection study and neither was included in Appendix E of the Draft EIS, but they are currently being considered for future potential repository evolution. The titles include parenthetical comments in italics that are intended to help the reader identify the specific attributes of the alternatives and features.

Table E-1. Design alternatives.

Alternative	Title	Text	Purpose	Status
1	Tailored Waste Package Spatial Distribution *(to improve heat distribution in the drifts)*	E.2.1.1	HM	CI
2	Low Thermal Load *(about 25 MTHM/acre)*	E.2.1.2	HM	PA
3	Continuous Postclosure Ventilation *(natural ventilation)*	E.2.1.3	HM	CI
4	Enhanced Access *(shielding to permit personnel access to the emplacement drifts)*	E.2.1.4	CO	CI
5	Modified Waste Emplacement Mode *(use natural shielding such as vertical emplacement of waste packages to permit personnel access)*	E.2.1.5	CO	CI
6	Viability Assessment Design *(85 MTHM/acre)*	E.2.1.6	HM	CI
7	Viability Assessment Design with Options *(ceramic coating, backfill and drip shield*[a]*)*	E.2.1.7	HM	CI
8	Modular Design (Phased Construction) *(phased construction of facilities to provide funding flexibility)*	E.2.1.8	CO	AE

[a] Drip shields are listed as a design feature in Table E-2.

The tables include a column titled text, which lists the section of this appendix that contains additional description of the alternative or feature.

The column titled Purpose indicates the purpose or nature of the alternative or feature with respect to repository performance. The codes for the entries are:

Purpose of design alternative or feature:

RT— Enhance the barrier to prevent release and transport of fission products

HM— Control heat and moisture in the repository to reduce the potential for corrosion of the waste packages

CO— Support cost and operation considerations

The column titled Status indicates the current disposition of each alternative or feature as follows:

Status:

PA— Included in the impact analysis of the flexible design for the Proposed Action

AE— Additional evaluation to be conducted

CI— Currently inactive *(but not eliminated from further consideration)*

NF— Not considered feasible in conjunction with the flexible design

Table E-2. Design features.

Feature	Title	Text	Purpose	Status
1	Ceramic Coatings *(on the waste package)*	E.2.2.1	RT	CI
2	Backfill *(in the emplacement drifts)*	E.2.2.2	RT	CI
3	Drip Shield *(over the waste package)*	E.2.2.3	RT	PA
4	Preemplacement Aging and Blending of Waste *(commercial spent nuclear fuel only)*	E.2.2.4	HM	PA
5	Continuous Preclosure Ventilation *(both forced ventilation and natural ventilation of emplacement drifts)*	E.2.2.5	HM	PA/AE[a]
6	Rod Consolidation *(commercial spent nuclear fuel only)*	E.2.2.6	HM	CI
7	Timing of Repository Closure and Maintenance of Underground Facilities and Ground Support *(consideration of the repository being open for 300 years or more)*	E.2.2.7	HM	PA
8	Drift Diameter *(of the emplacement drifts)*	E.2.2.8	HM	CI
9	Waste Package Spacing and Drift Spacing	E.2.2.9	HM	PA
10	Waste Package Self Shielding	E.2.2.10	CO	CI/NF
11	Waste Package Corrosion Resistant Materials	E.2.2.11	RT	PA
12	Richards Barrier *(to divert moisture away from the waste package by capillary action)*	E.2.2.12	HM	CI
13	Diffusive Barrier/Getter Under the Waste Package	E.2.2.13	RT	CI
14	Canistered Assemblies *(for commercial spent nuclear fuel only)*	E.2.2.14	RT	CI
15	Additives and Fillers *(inside the waste package)*	E.2.2.15	RT	CI
16	Ground Support Options *(to prevent rockfall in the emplacement drifts*	E.2.2.16	RT	PA
17	Near-Field Rock Treatment during Construction *(to limit seepage of water into the drifts)*	E.2.2.17	HM	CI
18	Surface Modifications *(to limit infiltration of water into the mountain)*	E.2.2.18	HM	CI
19	Repository Horizon Elevation	E.2.2.19	CO	CI
20	Higher Thermal Loading	E.2.2.20	HM	CI
21	Dry Handling *(of commercial spent nuclear fuel in the Waste Handling Building)*	E.2.2.21	CO	AE
22	Site Access Road *(from U.S. 95 to the North Portal on the west side of Fortymile Wash)*	E.2.2.22	CO	AE

[a] Natural ventilation for the preclosure period is undergoing additional evaluation.

The tables indicate that eight alternatives and 22 features have been identified for consideration in finalizing the repository design. One alternative and seven features have been integrated into the flexible design analyzed for the Proposed Action in the Supplement to the Draft EIS and in the Final EIS. One additional alternative and three additional features will be evaluated further as the design matures. The six alternatives and 13 features that are listed as currently inactive (CI) have not been eliminated from consideration, but they were not considered in the environmental impact analysis for the Final EIS. Self shielding of waste packages, feature 10, is not considered feasible in conjunction with the waste package design used for the Final EIS.

The following sections provide brief descriptions of each of the alternatives and features. For the alternatives and features that are subject to additional evaluation (status AE), preliminary information on potential benefits and environmental impacts is provided. The benefits and impacts for the alternatives and features included in the flexible design (status PA) are discussed in the body of the Final EIS; for those with an inactive status (CI), the potential benefits and impacts have not been discussed.

E.2 Design Alternatives and Features

The summary descriptions of the design alternatives and features provided in the following sections are composite descriptions using data and text from both Appendix E of the Draft EIS and from the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). The *License Application Design Selection Report* provides references for additional data and information on many of the design alternatives and features.

E.2.1 DESIGN ALTERNATIVES

As mentioned above, the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all) and this Appendix discusses eight design alternatives. Six of these alternatives are currently inactive and DOE did not consider them in the impact analysis for this EIS. One of the draft alternatives, low thermal load, has been incorporated in the flexible design evaluated in the Proposed Action. The remaining alternative, Modular Design, would be evaluated further as the final repository design matures. The following sections provide a brief description of the design alternative from the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). For the modular design, DOE has also provided a qualitative assessment of the potential benefits and environmental considerations should DOE adopt this alternative at a later time.

E.2.1.1 Design Alternative 1, Tailored Waste Package Spatial Distribution

This design alternative addresses the position and placement of specific types of waste in the repository block emplacement drifts to determine if the postclosure isolation performance of the repository could be improved. The Draft EIS design emplaced the waste packages in the order received, with the only restrictions being the total amount of heat per acre and adjacent package heat considerations. This design alternative evaluation identifies combinations of site characteristics and waste forms and packages that would provide improved waste isolation performance and that practicable engineering could support. An example application would be grouping waste package types into categories of hot, medium, and cold to even the temperature differences across the repository or in a drift.

E.2.1.2 Design Alternative 2, Low Thermal Load

The low thermal load design alternative formed the basis for the flexible design evaluated in the Supplement to the Draft EIS and the Final EIS. The basic premise of this alternative is that a lower thermal load would limit the temperature of the drift wall and host rock and, thereby, would reduce uncertainties in predicting thermal, chemical, mechanical, and hydrological effects. As demonstrated in the Supplement to the Draft EIS and this Final EIS, the lower-temperature repository operating mode could be achieved by varying certain operational parameters such as waste package spacing, ventilation rate and duration, and waste package loading.

E.2.1.3 Design Alternative 3, Continuous Postclosure Ventilation

The postclosure ventilation design alternative identifies a series of conceptual designs aimed at utilizing ventilation in the emplacement drifts during the postclosure period. The expected benefit provided by postclosure ventilation would be improved waste package performance. Improved performance could be achieved by limiting the amount of water or humidity contacting the waste packages, which would reduce corrosion. A ventilated repository could reduce the emplacement drift air temperature, as well as the relative humidity, rock saturation, and rock temperature.

E.2.1.4 Design Alternative 4, Enhanced Access

This design alternative considers the approach of providing sufficient radiation shielding for the waste packages to allow personnel access during handling and inspection operations. This, in turn, would simplify component design and operations. Access to the emplacement drifts would be provided so personnel could execute performance confirmation activities and maintenance.

E.2.1.5 Design Alternative 5, Modified Waste Emplacement Mode

In this design alternative, unshielded waste packages would be placed in a configuration where the repository's natural or engineered barriers would provide the personnel shielding. This alternative is similar to the enhanced access design in that personnel could access areas near the waste packages, but in this design alternative the waste packages would not have to be shielded. Various configurations for accomplishing the shielding using the natural and engineered barriers would be considered. 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.

E.2.1.6 Design Alternative 6, Viability Assessment Reference Design

The Viability Assessment reference design is equivalent to the high thermal load alternative (85 MTHM per acre) evaluated in the Draft EIS. The complete description of this design is presented in Chapter 2 of the Draft EIS.

E.2.1.7 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. Options considered include ceramic coatings, backfill, and drip shields (see Sections E.2.2.1, E.2.2.2, and E.2.2.3, respectively).

E.2.1.8 Design Alternative 8, Modular Design (Phased Construction)

This design alternative considers the effects of separating the Waste Handling Building, the Carrier Preparation Building, and the subsurface repository into multiple modules, structures, or phases to be constructed over time. Direct support facilities such as the Waste Treatment Building, the balance of the plant support facilities, and any additional facilities required for the support of early receipt or storage could also be phased.

Six alternative design concepts were considered to determine the impact on waste throughput quantities. These concepts were reviewed to determine how they would perform in relation to funding constraints, waste receipt and storage, and emplacement rates. Subsurface construction and phasing to meet estimated emplacement rates were reviewed to determine the most effective method.

DOE would evaluate this design alternative further as the repository design matures, and as funding forecasts were identified.

E.2.1.8.1 *Potential Benefits*

Modular design is an alternative that could reduce annual expenditures during construction if annual funding is constrained below that required for the Proposed Action.

E.2.1.8.2 *Potential Environmental Considerations*

Modular design is an alternative that would probably increase the total facility cost and the environmental impacts by about 20 to 30 percent. Constructing multiple facilities to handle the same capacity would increase nearly all impacts because many systems (for example, ventilation systems) would need to be partially duplicated and total building floor space would increase. In addition, construction of the later facilities would be carried out in parallel with nuclear operations on the site, which would result in the need for careful control and monitoring of construction activities. All of the impacts would likely be extended over a longer period. Annual impacts could remain nearly the same but total impacts would be likely to increase.

E.2.2 DESIGN FEATURES

This section describes the 22 design features, 20 of which DOE evaluated as part of the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). Seven of these features have been incorporated (some only partially) in the flexible design evaluated in the Proposed Action. Based on the current design, 13 of the features are either inactive or not feasible. For the features that are being evaluated for incorporation as the design matures, DOE has provided a qualitative assessment of their potential benefits and potential environmental considerations.

E.2.2.1 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 corroded. Several thermal processes produce high-density coatings on metals, and the range of materials that can be applied is extensive. The coating materials that could be considered include magnesium aluminate spinel, aluminum oxide, titanium oxide, and zirconia-yttria. This design feature is no longer under active consideration, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.2 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, could be considered. The waste packages would generate heat after emplacement, and this heat would tend to drive water away from the emplacement location. Backfill would act as insulation for the waste packages, keeping them hotter. The emplacement areas would stay hotter longer, which could retard the onset of waste package corrosion by delaying the onset of water contacting the packages. The waste packages would gradually cool off and become potentially vulnerable to corrosion caused by water and corrosive minerals dissolved in the water. In addition to providing thermal insulation, the backfill (without proposed drip shields) would provide some protection to the waste package from rockfall. This design feature is no longer under active consideration.

As discussed in Chapter 2, Section 2.1.2.4, backfill would be used for the Proposed Action for main drifts, access ramps, and ventilation shafts. The backfill for these drifts and shafts would be installed during closure. Backfill is not currently planned for use in the emplacement drifts.

E.2.2.3 Drip Shields

Drip shields over the waste packages would provide a partial barrier by diverting falling rocks and infiltrating water away from waste packages in an emplacement drift. Corrosion-resistant metals (titanium or Alloy-22), metals with ceramic coatings, and monolithic ceramics have been considered as drip shield materials. One option would be to place drip shields under backfill; another would be to place the drip shields over the backfill. Drip shields could be implemented with or without backfill.

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

For the Final EIS, DOE has incorporated the use of drip shields without backfill as part of the Proposed Action.

E.2.2.4 Aging and Blending of Waste

Pre-emplacement aging and blending of commercial spent nuclear fuel would provide mechanisms for managing the thermal output of a waste package and the total thermal energy that the repository would have to accommodate.

Aging the waste before emplacement would result in less variable (over time) thermal output of the waste packages and lower waste package temperatures.

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 and to lower peak waste package heat output.

Aging and blending would not be necessary for DOE spent nuclear fuel and high-level radioactive waste.

Both aging and blending would require additional facilities at the repository. A 5,000-MTHM-equivalent storage pool would be required to support blending and a large surface storage pad along with large storage casks would be required to support aging. The capability to age and blend commercial spent nuclear fuel has been incorporated as part of the Proposed Action in this Final EIS.

E.2.2.5 Continuous Preclosure Ventilation

During preclosure, a ventilation system would deliver a specified volume of air to the emplacements drifts containing waste packages. This continuous ventilation would reduce air and drift temperatures, and would carry away heat and moisture that could otherwise increase corrosion. The host rock would remain drier and cooler during preclosure compared to a repository (such as the Draft EIS design) where there was little ventilation.

The ventilation could be provided using forced flow driven by electric-motor-powered fans or by natural ventilation. Forced-flow ventilation is included in the Proposed Action and is discussed in Volume I of this Final EIS. The heat generated by the spent nuclear fuel and high-level radioactive waste could develop and maintain a temperature difference to drive passive ventilation of the emplacement drifts throughout the maximum time the repository would remain open. This is called *natural ventilation*. The heat from the waste could be used to draw cooler, drier external air through the intake shafts, across the emplacement drifts, and out the exhaust shafts (located at an elevation above the intakes), much the way heat from a fireplace draws air from a room and exhausts it through a chimney. Passive ventilation is used to regulate air temperature in buildings and has similar uses in large subsurface structures such as mines. Findings in numerous caves that are analogous to a deep geologic repository (DIRS 153849-DOE 2001, Section 2.1.5.4) support the idea that the environment of a naturally ventilated underground system could, under certain conditions, preserve materials for several thousand years and could greatly reduce waste package degradation.

Natural ventilation during preclosure is the subject of additional evaluation for potential future repository evolution. The environmental impacts of natural ventilation were evaluated in one of the lower-temperature operating modes for this Final EIS. Methods for implementing this feature would require further evaluation, as discussed below.

E.2.2.5.1 *Potential Benefits*

The primary benefit of natural ventilation for the removal of heat and moisture would be the reduction in energy use and reduction in maintenance compared to systems using forced-flow ventilation driven by electric fans, potentially required to operate for hundreds of years. Benefits of forced-flow ventilation are addressed in Chapter 2 as part of the Proposed Action.

E.2.2.5.2 *Potential Environmental Considerations*

Additional excavation could be required to optimize the repository configuration for natural ventilation. The actual number of emplacement drifts might not change, but the layout of drifts could vary slightly to accommodate additional or reoriented ventilation shafts. The sizes of the shafts might have to be increased. A backup forced ventilation system could be needed to provide "blast cooling" to support maintenance. Environmental impacts of forced-flow ventilation are addressed in Chapter 4 as part of the Proposed Action.

E.2.2.6 Rod Consolidation

Both pressurized-water reactor and boiling-water reactor fuel assemblies have fuel rods arranged in regular square arrays with rod-to-rod separations maintained by fuel assembly hardware. Rod consolidation would involve taking the fuel rods out of the arrays and bringing them into direct contact with one another. This would reduce the volume required by fuel assemblies and would allow increases in the capacity of waste packages or reduction in waste package size. The fuel assemblies would be consolidated by removing the fuel rods from the assembly and placing them in a canister. Each canister could contain fuel rods from one or more fuel assemblies. The canisters would then be loaded into the waste package. Nonfuel components (control rods, channels, etc.) would be separated from the fuel assemblies for disposal by other methods. The remainder of the assembly hardware would be disposed of separately. The consolidation process could occur in a pool or shielded dry environment. This design feature is no longer under active consideration because the concentration of thermal energy inherent in rod consolidation is not consistent with the flexible design operating modes.

E.2.2.7 Timing of Repository Closure and Maintenance of Underground Facilities and Ground Support

The timing of the repository closure design feature addresses the changes in performance criteria that result from consideration of a monitoring phase as long as 300 years, rather than the 100-year period from initiation of waste emplacement used in the Draft EIS design. Included in the design feature were requirements to facilitate keeping the repository open for an additional 200 years, the related cost implications, and a risk assessment. The maintenance of underground facilities and ground support design features was included in this design feature because the two features would be interrelated. Underground facilities and ground support would affect the level of maintenance in the emplacement drifts needed to accommodate an extended long-term repository service life. One benefit of a maintenance program would be that it could reduce the risk of rockfall in the emplacement drifts. This feature is included as part of the Proposed Action lower-temperature operating mode.

E.2.2.8 Drift Diameter

The diameter of the emplacement drift is influenced by a number of primary design features. Heat management strategies, emplacement mode, and emplacement equipment are major influencing factors. 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 moisture seepage into the drifts. These design considerations could affect repository performance. The drift diameter for the Draft EIS design was 5.5 meters (18 feet). The 5.5-meter drift diameter was maintained in the Supplement to the Draft EIS and in this Final EIS. DOE is not actively considering a change in drift diameter because other drift diameters do not enhance the performance or operation of the flexible design operating modes. The drift diameter for the flexible design was standardized at 5.5 meters (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.4).

E.2.2.9 Drift Spacing and Waste Package Spacing

Drift spacing is the distance between two consecutive drifts. Waste package spacing is the distance between the ends of two consecutive waste packages. For a given drift spacing, emplacement of waste packages can be arranged by using point load (waste package spacing based on individual package characteristics, such as mass content or equivalent heat output), or line load [waste packages emplaced nearly end to end with a 0.1-meter (0.3-foot) gap and with no consideration of individual waste package characteristics].

The point load approach to thermal analysis was used for the scenarios evaluated in the impact analysis for the Draft EIS design. Waste package spacing was based on the mass content of waste packages, to achieve an overall area mass loading from 25 MTHM per acre to 85 MTHM per acre for commercial spent nuclear fuel. The higher-temperature repository operating mode evaluated in the Final EIS is a line load configuration with 0.1-meter (0.3-foot) waste package spacing and 81-meter (270-foot) drift spacing. The lower-temperature repository operating mode evaluated in the Final EIS uses the 81-meter drift spacing but considers spacing ranging from about 2.1 to 6.4 meters (6.9 to 21 feet).

E.2.2.10 Waste Package Self-Shielding

In the repository designs evaluated to date, handling of waste packages in the emplacement drifts would be performed remotely, and human access to the emplacement drifts would be precluded if waste packages were 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 for 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. Because the amount of shielding would substantially increase the weight and size of the loaded waste packages, it is not considered feasible with the current waste package design. This design feature is no longer under active consideration.

E.2.2.11 Waste Package Corrosion-Resistant Materials

The Draft EIS design for the waste package used two concentric barrier layers: an outer A516 carbon steel corrosion-allowance material that would provide structural strength during handling, and an inner 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 improve long-term performance.

An upgrade of the waste package design replaced the corrosion-allowance barrier with a corrosion-resistant barrier and was evaluated in the Supplement to the Draft EIS and this Final EIS. Several combinations of materials were considered for the inner and outer layers. The combination selected was an outer shell of nickel-based Alloy-22 corrosion-resistant material and a stainless-steel (Type 316NG) inner shell, which would provide structural strength and corrosion resistance.

E.2.2.12 Richards Barrier

A Richards Barrier would be a special type of backfill consisting of a fine-grained material, such as sand, covering a coarse-grained material, such as gravel. The coarse-grained material, in turn, would cover the waste package, with the fine-grained material acting as a cap or cover for the coarse-grained material. The Richards Barrier would use the difference in permeability between the two backfill materials to divert water. Water entering the emplacement drift would flow in the fine-grained material and not enter the coarse-grained material. The water would travel to the edge of the fine-grained material and reenter the surrounding rock mass through cracks. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.13 Diffusive Barrier/Getter Under the Waste Package

The diffusive barrier component would be a loose, dry, granular material placed in the intervening space beneath each waste package and above the bottom of the emplacement drift to a sufficient depth and degree of compaction that would form a restrictive barrier to seepage. The getter component, a fine-grained material with an affinity for radionuclides, would be mixed with a matrix material and dumped into the invert recess. The combined material would be placed around the structural supports of the waste package to eliminate voids when the waste package was emplaced. This design feature is no longer under active consideration because of uncertainties in the long-term performance improvement of the repository and uncertainties in the long-term effectiveness of the material (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.1).

E.2.2.14 Canistered Assemblies

Placing commercial spent nuclear fuel assemblies in canisters at the Waste Handling Building before inserting them into disposal containers would provide an additional barrier and further limit mobilization of radionuclides if the waste package was breached. The canisters would be fabricated from a corrosion-resistant material (for example, Alloy-22 or a zirconium alloy). There would be three general concepts for the placement of fuel assemblies in canisters: (1) Canisters could be designed to hold individual fuel assemblies; (2) Canisters could be designed to hold a few assemblies, and (3) A large canister could be designed to hold multiple fuel assemblies and fit one canister per waste package. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.15 Additives and Fillers

Waste package additives and fillers (henceforth referred to simply as fillers) are materials that could be placed in a loaded waste package to fill the void spaces. These materials could have the following benefits for performance of the engineered barrier system: (1) retardation of radionuclide release from a breached waste package by absorbing radionuclides and providing resistance to advective transport; (2) displacement of the moderator from the interior of the waste package to provide additional defense-in-depth for criticality control; and (3) limitation on the amount of oxygen available for waste form alternation. In addition, various waste package filler options could provide such benefits as serving as a mechanical packing to inhibit movement of the waste form in the package, creating a barrier to the release of particulate radionuclides during a design-basis event, or providing cathodic protection of fuel and basket material. The disadvantages of additives and fillers include adding weight to the waste package, introducing the potential for additional corrosion or chemical reaction, and complicating the removal of material from the waste package if necessary following retrieval. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.16 Ground Support Options

Ground support in the repository is intended to ensure drift stability before closure. The selection of ground support options could affect repository waste isolation performance. Consideration of ground support options included 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. A concrete lining in the emplacement drifts was evaluated in the impact analysis for the Draft EIS. However, a number of postclosure performance assessment issues related to the presence of concrete in 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 a viable ground support candidate for emplacement drifts. The use of an all-steel lining system would provide a way to limit or eliminate 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. For the Supplement to the Draft EIS and this Final EIS, the all-steel ground support system for the emplacement drifts and a concrete liner support system for the main drifts and ventilation shafts were included as part of the Proposed Action.

E.2.2.17 Near-Field Rock Treatment

The function of rock treatment would be to limit the amount of water than could seep into the drift. The treatment would consist of injecting low-permeability grout into the cracks in a portion of the rock overlying each drift to lower the hydraulic conductivity of the rock in the treated zone. This would decrease seepage into the drift and thus reduce the amount of water that could contact the waste packages during postclosure. To meet seepage criteria, the rock treatment would have to perform while seepage toward the emplacement drift occurred.

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. This design feature is no longer under active consideration because it had limited potential to improve postclosure repository performance and its cost was high (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.2).

E.2.2.18 Surface Modification

Surface modifications could be a way to significantly reduce or eliminate the amount of water that could seep into the mountain from the surface and reach the waste packages. Two modification options were considered. The first option (alluvium option) would be to alter the ground surface to encourage natural removal of water to the atmosphere by evaporation from the ground surface and deep water removal by transpiration from plants. 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 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.

The second option (drainage option) is to alter the surface drainage to promote the rapid runoff of surface water by removing the thin layer of alluvium on the hilltops and slopes to expose the bedrock. It has been shown that where the alluvium is thin, it retains the surface water and allows it to infiltrate the unsaturated zone. Where bedrock is exposed on slopes, 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 (980-foot) buffer surrounding it. This design feature is no longer under active consideration since the lifetime of the alluvium layer was uncertain and the long-term effects of increased runoff could not be predicted. The feature also resulted in large short-term environmental impacts due to the extensive surface modification (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.3).

E.2.2.19 Repository Horizon Elevation

Two basic design concepts were considered for the repository horizon elevation feature. The first concept would be to relocate the repository to a higher evaluation. The higher elevation would be excavated in a single lithophysal unit, specifically the upper lithophysal unit. The second concept would be of a two-tier repository. This concept could allow for repository expansion if a decision was made to increase the waste inventory, provide performance improvements through thermal hydraulic effects, and increase flexibility in waste package emplacement strategies. This design feature is no longer under active consideration because further evaluation indicated severe construction problems including very steep access drifts, and the two-tier concept could not be shown to offer long-term performance improvement (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.4).

E.2.2.20 Higher Thermal Loading

This feature would increase the thermal loading of the repository by placing the waste packages close together, thereby increasing the density of heat sources in the repository. Although the total heat would not increase, it would be more concentrated because the repository would occupy a smaller area. This closer packing of waste packages could be done in one of three ways. The emplacement drifts could be excavated closer to one another. The waste packages would be placed closer together in each drift, with the emplacement drifts at their original reference spacing. The third possibility combines the first two options, resulting in closely spaced waste packages in closely spaced drifts. In all cases, the increased number of waste packages in a given area would create a higher concentration of heat, resulting in a higher thermal load to a given area of the repository. This design feature is no longer under active consideration.

E.2.2.21 Dry Handling of Spent Fuel in the Waste Handling Building

A dry handling capability in the Waste Handling Building would facilitate the handling of fuel assemblies, canisters, and waste packages in a dry environment. In addition, it would provide dry storage facilities for the temporary storage of fuel assemblies to support blending. The Waste Handling Building design would include hot cells, transfer facilities, and isolated maintenance cells to support receipt of truck and rail transportation casks, unloading of fuel assemblies and canisters from casks, opening of dual-purpose canisters, unloading of fuel assemblies from dual-purpose canisters, transfer of fuel assemblies to and from dry storage vaults, loading of fuel assemblies into disposal containers, transfer of filled disposal containers to the disposal container cell for emplacement preparation, and preparation of the empty transportation cask and dual-purpose canisters for offsite shipment. Two identical dry assembly transfer system lines and one dry canister transfer system would support the planned throughput rate. The estimated capacity of the dry fuel storage system would be 5,000 MTHM to support blending of the waste such that no waste package exceeded 11.8 kilowatts. This design feature might be considered and evaluated further in the future.

E.2.2.21.1 *Potential Benefits*

The dry handling approach potentially would have several operational advantages over the wet handling approach. A significant advantage is that the estimated throughput rate for the dry handling system would be about a third higher than that for an equivalent wet system, which would increase operational flexibility. Liquid wastes and worker doses during operation would be reduced substantially with respect to the corresponding values for a wet system. The dry handling approach would eliminate the need for assembly cooling in the cask preparation step and for drying the assemblies prior to disposal container loading. Dry handling would also eliminate the need to dewater shipping casks after unloading. In general, it would be an advantage to eliminate some of the challenges associated with water in pools and wet handling.

E.2.2.21.2 *Potential Environmental Considerations*

The space required for the dry handling facility would be about the same as the space required for equivalent wet handling if commercial spent nuclear fuel blending was not needed. If commercial spent nuclear fuel blending was required, the dry handling/storage facility would be larger than the wet facility because the spent nuclear fuel stored dry would have to be spaced farther apart than in wet storage. Accordingly, DOE could have to expand the overall Waste Handling Building site to accommodate dry handling. The use of construction materials such as concrete and steel would increase for the dry handling facility. As mentioned above, the dry handling approach would reduce worker doses and the generation of liquid waste. Conversely, the cost of building the dry handling facilities would be higher but the operation costs would be equal or less than those for wet handling.

E.2.2.22 Site Access Road

A new site access road would enable more direct, efficient, and safe travel for personnel and transportation of materials. A conceptual plan for the new access road involves the construction of an approximately 32-kilometer (20-mile) section of roadway from Amargosa Valley (formerly known as Lathrop Wells) at U.S. Highway 95 near the southwest corner of the Nevada Test Site to the Yucca Mountain site. The road would run in a predominantly northerly direction parallel to Fortymile Wash and would terminate at the Yucca Mountain site in the vicinity of the North Portal. Figure E-1 shows the route being considered. The road would have two 3.7-meter (12-foot)-wide travel lanes, and 2.4-meter (8-foot)-wide shoulders, and would consist of a 15-centimeter (6-inch)-asphaltic concrete pavement over a 30-centimeter (12-inch) aggregate base. This design feature might be considered and evaluated further in the future.

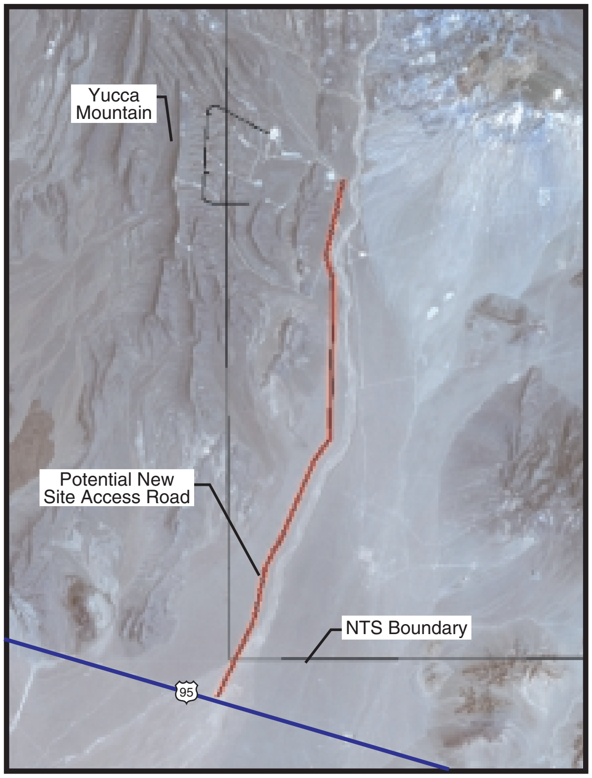

Figure E-1. Site access road.

E.2.2.22.1 *Potential Benefits*

The primary benefit from constructing a new site access road would be to facilitate more direct, efficient, and safe travel to the Yucca Mountain site. Current highway access to the Yucca Mountain site from the Las Vegas area to the east is by U.S. Highway 95 to the Mercury interchange near the southwest corner of the Nevada Test Site. From the Mercury interchange, the route travels about 110 kilometers (70 miles) to the Yucca Mountain site on existing roads that are old, narrow, and indirect, passing through about 10 intersections. Highway access from the west is by the existing Lathrop Wells Road for about 42 kilometers (26 miles) from U.S. 95 to the Yucca Mountain Site Central Support Site and then on to the site over about 27 kilometers (17 miles) of existing Nevada Test Site roads.

The new site access road would provide repository access from the Las Vegas area by travelling about 97 kilometers (60 miles) west past the Mercury interchange on U.S. 95 to the interchange at Amargosa Valley and then on the 32-kilometer (20-mile) section of newly constructed road to the repository site. Although this route would be about 16 kilometers (10 miles) longer than the existing route, it would be at least 10 to 20 percent faster and much safer, especially for transport vehicles carrying construction materials. Access to the repository site from the west would be directly from U.S. 95 on the 32-kilometer (20-mile)-long new access road and would be about half the distance of using the existing Nevada Test Site roads.

E.2.2.22.2 *Potential Environmental Considerations*

DOE would have to evaluate the environmental impacts of constructing the site access road. The 32-kilometer (20-mile)-long road would have about 12-meter (40-foot)-wide pavement and an assumed standard 3:1 slope and drainage beyond the paved shoulders, so the total road width would be about

24 meters (80 feet). The minimum total permanently disturbed area resulting from the construction of the road would be about 0.87 square kilometer (194 acres). Additional temporary disturbed area could occur from construction facilities, borrow pits, and laydown areas, which could total as much as 0.081 square kilometer (20 acres). These areas would be evaluated in an environmental survey to ensure that the impacts of constructing the access road were acceptable. The survey would focus on land use and ownership, cultural resources, hydrology, soils, and biological resources in and along the route. In addition, it would consider air quality, the safety of workers travelling the road, socioeconomic issues, and construction materials on a comparative basis with current routes.

E.3 Enhanced Design Alternatives

Enhanced Design Alternatives are combinations of the alternatives and design features described in the 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 were developed in the License Application Design Selection project. As stated in Section E.1.2.2, DOE chose Enhanced Design Alternative II for continued development and as the basis for the Final EIS analysis. For a description of the other Enhanced Design Alternatives, the methods used to evaluate them, and the results of the evaluations see the final *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all).

REFERENCES

107292	CRWMS M&O 1999	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1999. *License Application Design Selection Report.* B00000000-01717-4600-00123 REV 01 ICN 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990908.0319.
101779	DOE 1998	DOE (U.S. Department of Energy) 1998. *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Overview and five volumes. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0027; MOL.19981007.0028; MOL.19981007.0029; MOL.19981007.0030; MOL.19981007.0031; MOL.19981007.0032.
153849	DOE 2001	DOE (U.S. Department of Energy) 2001. *Yucca Mountain Science and Engineering Report.* DOE/RW-0539. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010524.0272.