DOE/RW--99002018

Reference Design Description

for a

Geologic Repository

Revision 02

January 1999

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MASTER

Civilian Radioactive Waste
Management System
Management & Operating
Contractor

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SUMMARY OF CHANGES

Revision 00	Initial issue
Revision 01	Added Primary Repository Performance Parameters (pages 8 & 9), clarified use of co-disposal container and updated dimensions of the canistered fuel-waste package assembly (page 41), corrected the time period to maintain the option to retrieve in order to be consistent with the Mined Geologic Disposal System Requirements Document (page 43), Waste Emplacement System details expanded/clarified (page 45), updated the EBS Design Options (page 58 and 59) and editorial text/graphic changes.
Revision 02	Updated to reflect the Viability Assessment design.

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Concept for Civilian Radioactive Waste Management System

Spent Nuclear Fuel and High-Level Radioactive Waste

- Load canisters or casks
- On-site storage
- Prepare for transport

Interim Storage Option (if required by law)

- Transfer commercial spent nuclear fuel assemblies to canisters
- Transfer commercial canisters to storage modules
- Storage
- Retrieve and prepare for transport
- Close interim storage facility
- Decommission interim storage facility

WMS2.CDR.121.RDD/01-13-99

INTRODUCTION

This Reference Design Description explains the current design for a potential geologic repository that may be located at Yucca Mountain in Nevada. It describes the proposed design for a surface facility, subsurface repository, and waste packaging; it also presents the current design of the key engineering systems for the final four phases: operations, monitoring, closure, and postclosure. In addition, this Reference Design Description reviews the expected long-term performance of the potential repository. In accordance with current law, this design does not include an interim storage option.

This design will protect the public and the environment by allowing disposal of highly radioactive material received from government-owned spent fuel custodian sites, high-level waste sites, and commercial spent fuel sites. All design elements will meet applicable Federal, State, and local regulations governing the disposal of high-level radioactive waste.

Since developing such a repository is very complex, the design will move forward in four stages: Viability Assessment, Site Recommendation, License Application, and construction. This document presents the design as submitted in the Viability Assessment and will be updated as the design process moves forward. As more cost-effective solutions, technical advancements, or changes to requirements occur, details presented here may change significantly.

The U.S. Department of Energy's Office of Civilian Radioactive Waste Management is developing a system that includes this potential repository. This waste management system integrates acceptance, transportation, storage, and disposal of spent nuclear fuel and high-level radioactive waste. Acceptance and transportation will be handled by Regional Service Contractors under contract to the U.S. Department of Energy. The U.S. Nuclear Regulatory Commission, through licensing, will independently review and approve the safety of the system.

This document has six major sections. Section I describes the physical layout of the proposed repository. The second section describes the 4-phase evolution of the development of the proposed repository. Section III describes the reception of waste from offsite locations. The fourth section details the various systems that will package the waste and move it below ground as well as safety monitoring and closure. Section V describes the systems (both physical and analytical) that ensure continued safety after closure. The final section offers design options that may be adopted to increase the margin of safety.

Table 1.
Spent Nuclear Fuel and High-Level Waste
to be Accepted at the Repository

Type	Amount (MTHM)*
Commercial Spent Nuclear Fuel	63,000
Commercial High-Level Waste	640
Defense High-Level Waste	4,027
DOE Spent Nuclear Fuel	2,333
Total	70,000

Table 2.
Annual Repository Receipt Rates

Year	Commercial Spent Nuclear Fuel (MTHM)	Commercial High-Level Waste, Defense High-Level Waste, and DOE Spent Nuclear Fuel (MTHM)
2010	400	TBD**
2011	600	TBD
2012	1,200	TBD
2013	2,000	TBD
2014	3,000	TBD
2015	3,000	400
-	3,000	400
-	3,000	400
-	3,000	400
2031	3,000	400
2032	3,000	200
2033	1,800	0

*MTHM = Metric Tons Heavy Metal

**TBD = To Be Determined

REQUIREMENTS FOR REPOSITORY REFERENCE DESIGN

The following Act and Federal regulations are the primary requirements governing the design of the proposed repository:

- The Nuclear Waste Policy Act of 1982, 42 USC 10101 et seq.
- 10 CFR 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories" NOTE: The Nuclear Regulatory Commission (NRC) has published a draft 10 CFR 63 to replace 10 CFR 60 for Yucca Mountain
- 10 CFR 20, "Standards for Protection Against Radiation"
- 10 CFR 73, "Physical Protection of Plant and Material"
- 29 CFR 1910, "Occupational Safety and Health Standards"
- 29 CFR 1926, "Safety and Health Regulations for Construction"
- 10 CFR 960, "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories"
- 40 CFR 197, "Environmental Radiation Protection for Management and Disposal of High Level Waste" NOTE: The United States Environmental Protection Agency will publish a draft 40 CFR 197 to replace 40 CFR 191.

The potential repository will be designed with sufficient flexibility to accommodate additional features. The design will not preclude waste retrieval both during waste emplacement operations and for 100 years after initial emplacement.

All site-generated hazardous, low-level radioactive, and mixed waste will be collected and packaged for transport to government approved off-site facilities for disposal. Hazardous, non-hazardous, and radioactive waste will be kept separated during normal operations to limit generating mixed wastes.

The potential repository will be capable of accepting 70,000 metric tons heavy metal or equivalent of spent nuclear fuel or high-level waste as shown in Table 1. Table 2 specifies the annual receipt rates for the repository. The repository will not accept or dispose of hazardous waste that is subject to the requirements of the Resource Conservation and Recovery Act of 1976.

The repository will be capable of receiving (by road and rail) and packaging (including opening non-disposable canisters) the following types of waste:

- Individual commercial spent nuclear fuel assemblies
- Commercial spent nuclear fuel in disposable canisters (multi-purpose canisters/large canisters)
- Commercial spent nuclear fuel in non-disposable canisters
- DOE and Navy spent nuclear fuel in disposable canisters (large or small canisters)
- Commercial and defense high-level waste, including immobilized plutonium, in small disposable canisters.

The emplacement area will have an areal mass loading ranging between 80 and 100 metric tons heavy metal and be located at least 200 meters below the ground surface.

Repository Site

SITELYOUT.COR.121.RDD/12-1-98

I. PHYSICAL LAYOUT OF SITE

Repository Site

Yucca Mountain is a potential site for a geologic repository. It is located in an area of uninhabited desert on Federal land in Nye County in southern Nevada, about 160 kilometers (100 miles) northwest of Las Vegas. The potential site will include surface and subsurface facilities.

Engineering standards will determine the arrangement of surface repository facilities for safe and efficient operations. The following are being considered:

- Subsurface accesses
- Radiological exposure boundaries
- Flood areas, fault zones, and meteorological patterns
- Support for surface and subsurface operations
- Preclosure radiological safety
- Minimization of environmental impact.

The surface location will consist of the following four major areas:

- North Portal area: This 80-acre area will contain the radiologically controlled area (including the nuclear waste handling facilities) and the rest of the area support facilities. This area will receive and package the waste for emplacement.
- South Portal area: This 30-acre area at the southern entrance to the potential repository will support the excavation of the underground area. Facilities for maintenance, warehousing, material staging, security, and transportation will be located here.

- Emplacement exhaust shaft area: This 3-acre site is located on the surface at the opening of the exhaust shaft. Facilities in this area will contain the ventilation exhaust fans and support their maintenance.
- Development intake shaft area: This 3-acre site is located on the surface at the opening to the intake shaft and will have a facility to house the development intake fans and auxiliary hoisting system.

The subsurface location will include the north and south ramps which will allow access to the emplacement block located in a welded tuff formation. This strong volcanic rock responds well to mechanical excavation and forms stable openings with appropriate ground support. The emplacement block will be located above the water table in the unsaturated region of the site.

The potential site for the emplacement block location was chosen because investigations indicated that this area is free of significant faults.

The waste will be placed in underground drifts (horizontal tunnels) located in the emplacement block. The distance between the drifts and the spacing of the waste packages within the drifts will be calculated to provide an areal mass loading of about 85 metric tons heavy metal for commercial spent nuclear fuel waste packages. High-level waste packages will be placed in drift areas between the commercial spent nuclear fuel packages.

North Portal Area

North Portal Area

Waste materials will be received and packaged for emplacement in an 80-acre area located at the northern entrance (North Portal) of the potential repository. Radioactive materials will be processed in the radiologically controlled area and support activities carried out in the remaining plant areas.

The radiologically controlled area will include the following facilities:

- Waste handling building, where spent nuclear fuel assemblies and disposable waste canisters will be put into disposal containers
- Waste treatment building, where low-level waste will be treated for off-site disposal

- Transporter maintenance building, where vehicles used to transport and emplace waste will be serviced
- Airlock building for ventilation during construction and operations
- Carrier preparation building, where shipping casks will be prepared for removal from rail or truck carriers.

The remaining plant area includes the following facilities: security stations, administrative building, fire and medical center, warehouse, central shops, motor pool and facility service station, mock-up building, utility building, change house, switchgear building, water tanks, and visitor's center.

Subsurface Facility

Subsurface Facility

The subsurface facility will include main tunnels, accesses, alcoves, and widely-spaced emplacement drifts. The facility's physical location, general arrangement, and the mountain's natural geologic barrier support long-term waste isolation. The subsurface facility provides for initial isolation of the waste by locating the emplacement drifts away from major faults and above the water table.

The subsurface facility includes:

- Two inclined access ramps
- Two vertical ventilation shafts
- Waste emplacement block with:
 - Service main drifts
 - Exhaust main drifts
 - Waste emplacement drifts
 - Performance confirmation drifts.

The ramps, shafts, and drifts will be sealed during the closure phase.

The waste emplacement block will be located at least 200 meters (656 feet) below the surface and at least 100 meters (328 feet) above the water table. At a depth of 200 meters, most of the proposed repository emplacement area will be at least 300 meters (984 feet) or more above the water table. (However, a potential expansion area to the north of the main emplacement area may come as close as 100 meters [328 feet] to the water table.) The block will cover 300 hectares (741 acres) and will accommodate approximately 10,200 waste packages in a large waste-package, high thermal-load configuration. The waste emplacement drifts in the block will run in an approximate east-west direction and will include about 117 kilometers (73 miles) of drifts.

The facility will have two types of main drifts that will be mechanically excavated:

- The service main drifts (including ramps) for access will have the following features:
 - 7.6 meters (25 feet) in diameter
 - Maximum grade of 3 percent on ramps to accommodate rail transport.
- The exhaust main drift for ventilation will have the following features:
 - 7.6 meters (25 feet) in diameter
 - Location 10 meters (33 feet) below the emplacement drifts
 - Connection to emplacement drifts by a series of ventilation raises.

Waste emplacement drifts also will be excavated mechanically:

- 5.5 meters (18 feet) in diameter
- 28 meters (92 feet) spacing between centers of emplacement drifts
- 900 meters (2950 feet) to about 1200 meters (3940 feet) in overall length with a raise from the exhaust main drift near the center of the emplacement drift
- Remotely controlled doors at the entrances to control access
- Raised floor above the main drift to allow a waste package to be off-loaded directly out of the transporter in preparation for emplacement.

Approximately 5 percent of the emplacement drifts will be completed before beginning waste emplacement operations. The remaining 95 percent will be completed in phases during waste emplacement operations.

Subsurface Ventilation System

Subsurface Ventilation System

The Subsurface Ventilation System will support operations of the subsurface repository by providing:

- Air to personnel
- Confinement of radioactive particles in the unlikely event of a release
- Limited temperature control of the underground facility based on air-flow volume and outside air temperature.

The development and emplacement operations will be physically separated from each other; each will have its own ventilation system and ramp access. A high-efficiency particulate air (HEPA) filtration system will trap particulates in the unlikely event of a radioactive release.

The system will consist of ducting, fans, seals, and electronic controls. It will interact with the surface for air intake and exhaust, electric power, and monitoring. Most major equipment will be located above ground.

During operations, underground openings will continue to be developed without interfering with waste emplacement. Separation of the two activities will be maintained using temporary walls (isolation air locks).

Two separate, independent ventilation systems will operate simultaneously during repository operations. One system will provide ventilation for the excavation operations required to develop the emplacement drifts, while the other will supply air to the waste emplacement operations. Temporary walls (isolation air locks) in the main drifts at the points that divide the two sides will

separate ventilation of the two systems. These temporary walls will be moved to new points in the main drifts to provide access to newly excavated drifts for waste emplacement. Each area will have its own dedicated fans with appropriate backup capability.

The ventilation system on the subsurface development (excavation) side will:

- Force air into the subsurface excavation drifts by way of fans at the intake shaft
- Exhaust air through the south ramp
- Maintain air pressure on the excavation side above the air pressure on the emplacement side.

The ventilation system on the emplacement side will:

- Pull air into the north ramp and emplacement areas using fans in the exhaust shaft
- Exhaust the air through the exhaust shaft
- Maintain a lower air pressure than on the excavation side of the subsurface layout
- Contain HEPA filters that will activate in the unlikely event subsurface contamination is detected.

This combination of systems will ensure that even in the event of one system shutting down, the pressure differential between development and emplacement will be maintained. Thus, any potential radioactive releases will be confined to the emplacement side.

Ground Control System

PRECAST CONCRETE LINING

CAST-IN-PLACE CONCRETE LINING

**STEEL SETS AND
STEEL LAGGING**

GCS CDR.121 RDD4-2-98

Ground Control System

The Ground Control System will provide for the safe construction and operation of the subsurface facility (main and waste emplacement drifts) and consists of a concrete lining, steel sets, or rock bolts for structural support in the main and emplacement drifts.

For the planned 100-year operational lifetime, the maintenance philosophy for underground openings is to have robust ground support so that routine maintenance will not be necessary once the waste packages are emplaced. Shafts, ramps, main drifts, and performance confirmation drifts that do not have high temperatures or radiation levels during normal operations can rely on periodic, planned maintenance.

The Ground Control System will consist of the structures installed within the excavated openings or reinforcement made to the rock surrounding the openings. Two ground control systems are under consideration for the emplacement drifts. The current design uses **precast concrete lining** in 90 percent of the emplacement drifts to ease installation, provide superior quality control, and minimize maintenance requirements.

For the remaining 10 percent of the emplacement drifts, steel sets with steel lagging will be used to allow scientists to analyze and survey rock formations (i.e., mapping). The steel sets will be installed during excavation. Once mapping is completed the steel

lagging will be installed. Design analysis has determined that **steel sets with steel lagging** are a more effective solution than the previously identified (in earlier document versions) **cast-in-place concrete lining** in the mapping areas because of possible stress fractures in the concrete from temperature changes.

Cast-in-place concrete linings currently are planned for the access ramps and main drifts.

The Ground Control System will be selected and designed to:

- Provide a robust support system with minimal maintenance requirements
- Maintain stable underground openings under the range of anticipated conditions, during the operations and monitoring phases, and during decommissioning
- Facilitate mapping of the rock mass in selected areas.

Special types of concrete are being evaluated to minimize geochemical interaction between concrete and the emplacement environment.

Phases of Repository Evolution

1. SITE
CHARACTERIZATION
PHASE

AND

2. CONSTRUCTION
PHASE

REPOHAZ.CDR 121.RDD/12-1-98

II. PHASES OF REPOSITORY EVOLUTION

Of the six phases that comprise the evolution of the potential repository, five are explained below: site characterization, construction, operations, monitoring, and closure. The sixth, postclosure, is explained in Section V.

1. Site Characterization Phase

This phase will include gathering and evaluating data to propose a site recommendation and, if warranted, prepare a License Application. The Exploratory Studies Facility will be constructed during this phase to help evaluate the suitability of Yucca Mountain for the location of a geologic repository.

2. Construction Phase

This phase will begin after receiving a construction authorization from the Nuclear Regulatory Commission. It includes building and equipping the surface facilities, modifying the Exploratory Studies Facility to become one of the main service drifts, continued excavation and equipping of subsurface facilities, manufacture of disposal containers, demonstrating selected repository operations, and gathering data to verify repository performance predictions.

3. Operations Phase

The operations phase consists of three activities: receiving, handling, and emplacement of waste.

Receiving. After the Nuclear Regulatory Commission issues a license amendment to receive and possess waste, the potential repository will receive waste transportation casks by rail or truck. The casks will be delivered to the carrier

preparation building, prepared, and then moved to the waste handling building. (Empty transportation casks will be returned to the Regional Service Contractors for re-use.)

Handling. The casks will be opened and the waste removed. The waste then will be loaded and sealed in a disposal container, thus creating a waste package. Next, the waste package will be loaded into a transporter and moved to the underground emplacement location.

Emplacement. The waste package will be off-loaded in the emplacement drift and set in place using a remotely controlled gantry.

4. Monitoring Phase

The monitoring phase will continue after all waste packages have been emplaced. This will include continuing to collect and analyze data to confirm predicted performance as well as to maintain the subsurface facility. The capability to retrieve the waste packages will also be maintained.

5. Closure Phase

The closure phase will begin after the license amendment to close the repository has been received from the Nuclear Regulatory Commission. Closure will include backfilling and sealing access openings and may include placing drip shields and/or backfilling the emplacement drifts. The surface facilities will be decontaminated and dismantled.

Waste Receiving Operations

WASTRECV.CDR.121.RDD

III. WASTE RECEIVING OPERATIONS

The potential repository will receive high-level waste and spent nuclear fuel in shielded shipping casks which will be licensed for nuclear waste transport by the Nuclear Regulatory Commission and transported on rail or highway carriers. Approximately 700 casks will be received in the peak year. Rail lines to the site will also support the transportation of large shipping casks. Truck access to the site will also be provided for legal weight trucks and, if necessary, heavy haul trucks.

The shipments will pass through a security station and receive a **security inspection** before entering the radiologically controlled area near the North Portal. After the security inspection, an on-site vehicle will move the shipment to **cask/carrier parking** in the controlled area. The off-site vehicle will then be released for other duties.

Once on site, the Carrier/Cask Transport System will handle the shipment. The shipment will be moved to the carrier preparation building where it will receive **carrier preparation and inspection**. The building, a single-level metal structure with about 20,000 square feet of floor space, will contain the Materials Handling System. The building will house:

- Staging for truck or rail carriers
- Work platforms
- Two 10-ton bridge cranes
- Two gantry-mounted manipulators
- An office area.

The Materials Handling System will:

- Remove or retract the personnel barriers from the cask
- Perform a radiological survey
- Remove the cask impact limiters.

When the carrier and cask have been prepared for cask removal and the waste handling building is ready to receive a waste shipment, the Carrier/Cask Transport System will move the carrier and cask to the waste handling building.

After waste removal, the carrier with the empty cask will be prepared for shipping--including decontamination to Federal Standards--and will be moved from the waste handling building back to the carrier preparation building. The impact limiters and personnel barriers will be reinstalled. The carrier and empty cask will be returned to the carrier parking area for removal from the repository by an off-site vehicle.

A washdown station will be located within the radiologically controlled area in case a carrier requires cleaning.

Waste Handling Operations

WFOPS 2.CDR.12/01-14-99

IV. WASTE HANDLING OPERATIONS

Once the cask has been prepared for removal from the carrier, the loaded shipping casks will be transported to the waste handling building near the North Portal. The waste will then be transferred to disposal containers, welded closed, inspected, and loaded into an underground transporter. The waste handling building will house a variety of support systems to provide a secure, controlled environment that protects the workers and confines potential contamination. Operations will be performed in the waste handling building by the four systems listed below.

- The **Carrier/Cask Handling System** will remove loaded casks from the truck and rail carriers and place empty casks and empty dual purpose canisters on carriers. A dual purpose canister will be licensed by the Nuclear Regulatory Commission for transportation and dry storage but will not be licensed for disposal in the repository

- The **Assembly Transfer System** will receive spent nuclear fuel assemblies in casks and dual purpose canisters and transfer the assemblies to disposal containers
- The **Canister Transfer System** will receive casks containing waste in disposable canisters and transfer the canisters to disposal containers
- The **Disposal Container Handling System** will weld the lids onto disposal containers and load the waste packages (loaded and sealed disposal containers) into a shielded transporter for transport to the underground emplacement area

The Waste Package Remediation System will sample and inspect retrieved waste packages and repair or open waste packages that are off-normal or recovered for performance checking. (See page 26 for the location in the waste handling building.)

A more detailed description of the first four systems is provided in later sections of this document.

[illegible]

DOCUMENTS.RDD.MGDSDOC.P65/01-99

Waste Handling Building

The waste handling building will provide the structures, systems, and components that support waste packaging operations, including electric, security, fire protection, ventilation, communications, and radiological monitoring. The waste handling building will provide a controlled environment for dry and wet handling operations. It will confine contamination and provide radiological protection for personnel and the public. To the greatest degree practicable, the design and operating concepts for the facility will incorporate equipment and procedures already approved by the Nuclear Regulatory Commission and in use at other licensed nuclear facilities.

The waste handling building will include the waste handling areas, support areas, and features described below:

- Six-level concrete structure
- About 440,000 square feet of usable floor space
- One large bay for loading and unloading truck and rail carriers
- Three assembly transfer lines, each with a cask preparation area, a pool for unloading and staging assemblies, and a fuel assembly handling cell for loading individual assemblies into disposal containers
- Two canister transfer lines, each with a cask preparation area and one canister transfer cell for transferring canisters into disposal containers

- One large cell for handling, staging, and welding disposal containers
- One small cell for loading a waste package onto an underground transporter
- One general purpose recovery cell for remediating off-normal waste packages
- Operating galleries to view and control transfer and handling operations
- Maintenance areas for contaminated equipment
- Laboratories, mechanical equipment rooms, electrical equipment rooms, and tooling and maintenance store rooms
- Support areas for administration, personnel, central control, and security access controls
- A large work area for empty disposal container receiving, preparation, and staging.

Selected handling operations will be carried out underwater in pools using remote handling equipment to protect operators from radiation. Operations involving spent nuclear fuel assemblies, canisters, and disposal containers will also be conducted remotely in shielded dry cells to protect workers. The remote equipment will be designed for ease of decontamination and maintenance. Interchangeable components will be provided where possible. Remotely operated equipment will be either manually or automatically controlled.

Carrier/Cask Handling System

CARRIER CDR 121 RDD/6-3-97

Carrier/Cask Handling System

The Carrier/Cask Handling System will remove loaded casks and dual purpose canisters from the truck and rail carriers and replace empty casks and dual purpose canisters on carriers for shipping off-site.

Operations will begin as a truck or rail carrier is moved to the waste handling building by the on-site transporter. Before entering the building, the impact limiters and personnel barriers will have been removed or retracted. Road grime may be removed at a **carrier washdown station** before entering or after leaving the **carrier bay**. The large, open carrier bay will have the following features:

- Two flush-mounted rail spurs
- A 125-ton (minimum) bridge crane
- Lifting yoke staging areas
- Access to the cask carts.

A large bridge crane will re-orient the cask from horizontal to vertical and place it on a transfer cart. The remotely operated cart will move into one of the five waste transfer lines. Where possible, operations on loaded casks will be conducted remotely to limit worker exposure to radiation. Empty casks and empty dual purpose canisters with overpacks will be removed from the waste transfer lines and loaded on the carriers in the reverse sequence.

In a peak year, the system will receive about 700 loaded casks and ship out about 400 empty dual purpose canisters in overpacks. The 700 casks will be a combination of casks with bare spent nuclear fuel, dual purpose canisters, high-level waste and DOE spent nuclear fuel canisters, or multi-purpose canisters. Since the peak yearly receipts for the various types of waste casks will not be received in the same year, the overall peak yearly receipts would not exceed 700 loaded casks.

Assembly Transfer System (page 1 of 2)

WETLINE CDR 121.RDD/12-1-98

DPC = dual purpose container

Assembly Transfer System

The Assembly Transfer System will receive casks containing uncanistered fuel assemblies and dual purpose canisters and will transfer the assemblies to disposal containers. The empty shipping casks and dual purpose canisters will be prepared for off-site shipment. In a peak year, the assembly transfer system will receive, then transfer about 12,000 assemblies from 540 commercial spent nuclear fuel casks into 380 disposal containers. The system will support the waste packaging operations and will be located in the waste handling building.

Operations will begin as a vertically loaded shipping cask enters through an **airlock**, into one of the three identical assembly transfer lines from the Carrier/Cask Handling System. The cask, on a remotely operated cart, will pass into a **cask preparation area**. The preparation area will include:

- Preparation pits
- A manipulator
- A preparation manifold
- Decontamination equipment
- A 125-ton (minimum) bridge crane.

In the preparation area, a cask containing uncanistered fuel assemblies will be prepared by remote control for unloading by sampling the interior gas, venting, cooling, filling the cask with water, and loosening the lid bolts. A large bridge crane then will move the cask into a **cask unloading pool**. For casks containing a dual purpose canister, preparation includes remote removal of the cask lid and preparing the dual purpose canister for unloading by sampling the interior gas, venting, cooling, and filling the dual purpose canister with water.

The decontamination equipment will be used after assembly transfer to prepare empty casks and dual purpose canisters for shipment off site.

In the pool, depending on the cask type, either the cask shield will be removed (thus providing direct access to the fuel assemblies) or the dual purpose canister will be unloaded from the cask with the bridge crane. The dual purpose canister's welded lid will be cut open. The exposed assemblies will be transferred with a wet fuel-handling machine to baskets in the **assembly staging pool** or directly to an underwater transfer cart. The cart will transfer the assembly staging basket up through an inclined canal to the assembly handling cell.

The empty cask will be transferred to the preparation area for dewatering and decontamination. The empty dual purpose canister will be dewatered in the pool area and transferred to the preparation area for overpacking and decontamination. The overpacked dual purpose canister and lid will be moved on the cart to the Carrier/Cask Handling System for shipment off site.

Each pool includes:

- The unloading and staging area
- A wet fuel transfer machine
- Staging baskets and racks for 264 to 528 assemblies
- Dual purpose canister cutting tools
- A dewatering and pool water system
- Incline and cross-transfer cart
- Underwater cameras.

Assembly Transfer System (page 2 of 2)

Assembly Transfer System (Continued)

In the **assembly handling cell**, a vacuum drying system will dry the assemblies before their transfer to an empty disposal container by a dry-fuel-handling machine. The assembly handling cell will include:

- The dry-fuel-handling machine
- A mating port system
- Two vacuum drying vessels
- Five-foot thick shield walls
- Cameras and shield windows
- A 15 ton (minimum) bridge crane
- A manipulator
- Maintenance bay to support maintenance and repair.

During the transfer, the disposal container will be mated to the cell through a transfer port to limit any spread of contamination. All operations will be conducted by remote control.

Disposal container load and decontamination cells will be located below the transfer port. The disposal container loading and decontamination cells will include:

- A disposal container transfer cart
- Decontamination equipment
- Nitrogen inerting equipment
- Shield walls
- Cameras
- Shielded doors and windows.

In these cells, the loaded disposal container will receive a temporary lid, will disengage from the port, and will be transferred on a cart to the decontamination cell.

The disposal container will be decontaminated, temporarily filled with nitrogen, and temporarily sealed before transfer to the Disposal Container Handling System for permanent welding. All operations will be conducted by remote control.

Canister Transfer System

Canister Transfer System

The Canister Transfer System will receive casks containing waste in disposable canisters (including large disposable canisters, high-level waste canisters, DOE spent fuel canisters, and naval fuel canisters) and transfer the canisters to disposal containers. Empty shipping casks will be prepared for off-site shipment. In a peak year, the system will receive and transfer about 500 small defense high-level waste canisters from 100 larger casks into about 100 disposal containers and has the capability to transfer about 300 large canisters (e.g., multi-purpose canisters) containing spent fuel assemblies. This system will support waste packaging operations and will be located in the waste handling building.

Operations will begin as a vertically-loaded shipping cask enters, through an **airlock**, into one of the two identical canister transfer lines from the Carrier/Cask Handling System. The cask, on a remotely operated cart, will pass into a **cask preparation and decontamination area**. This area will include:

- A cask transfer cart
- A cask preparation manipulator
- A cask sampling/venting system
- Decontamination equipment
- Cameras
- Shielded doors and windows.

In this area, a cask containing a disposable canister will be prepared for unloading by remotely sampling the interior gas, venting, and remotely de-tensioning the lid bolts. A cart will move the prepared cask into the canister transfer cell. Operations on a loaded cask generally will be conducted by remote control.

The decontamination equipment will prepare empty casks for shipment after waste transfer.

In the canister transfer cell at the **unloading station**, the cask shield will be removed and the canister(s) will be lifted from the cask.

The canister transfer cell will include:

- A 65-ton (minimum) bridge crane
- A disposal container loading manipulator
- A staging rack for approximately 20 small canisters
- Various lifting fixtures
- A disposal container transfer cart
- Shield walls
- Cameras
- Shielded doors and windows.

At the **disposal container loading station**, a large canister will be loaded directly into a disposal container and small canisters will either be loaded directly into a disposal container or accumulated in a staging rack until enough compatible canisters are available to fill a co-disposal container (i.e., a disposal container which contains both high-level waste and spent nuclear fuel, see page 41). The loaded disposal container will be transferred to the Disposal Container Handling System on a cart for welding. All operations will be conducted by remote control.

A crane maintenance bay will support maintenance and repair operations.

Disposal Container Handling System

Disposal Container Handling System

The Disposal Container Handling System will weld the lids on the loaded disposal container. The waste package (a loaded and sealed disposal container) will then be placed into a shielded transporter for movement to the underground emplacement area. The system will provide empty (new) disposal containers to the Assembly Transfer System (ATS) and the Canister Transfer System (CTS). In a peak year, the system will receive, seal, and transport underground about 525 waste packages. The system will support waste packaging and be located in the waste handling building.

Operations will begin as a loaded disposal container enters the **disposal container handling cell** from one of the five waste transfer lines (i.e., from the ATS or the CTS). The disposal container (which is in a vertical position) will be set on a remotely operated cart and moved within the reach of a large bridge crane. The crane will move the waste package to a **disposal container staging area** or directly to a **disposal container welding station**. At the welding station, the inner lid will be welded and inspected and the disposal container will be filled with helium. The outer lid will then be welded and inspected. The robotic welder will be mounted on a gantry that can be moved through the cell wall and into a maintenance bay. The disposal container will be rotated (using a turntable) during welding with the welding head held stationary.

The welded and loaded disposal container (waste package) will be lifted from the weld station and placed in a staging fixture or directly in a **waste package tilting fixture**. At the tilting fixture, a crane will lower the waste package onto a horizontal transfer cart. The cart will transfer the waste package from the disposal container cell to a **waste package transporter loading cell**, then into the **waste package transporter airlock**. All disposal container cell

operations will be conducted by remote control. The disposal container handling cell will include:

- A 110-ton overhead bridge crane
- Eight welding stations and weld station turntables
- Four jib cranes to support the welders
- 20 disposal container staging fixtures
- Six vertical disposal container transfer carts (five for the transfer lines, one for the empty disposal container)
- A horizontal transfer cart and tilting fixture
- A manipulator and disposal container lifting yoke
- Shield walls, shielded doors and windows
- Cameras.

The cell will have a crane maintenance bay to support maintenance and repair operations.

In the waste package transporter loading cell, an overhead lifting system will lift the waste package from the cart and the cart will be returned to the disposal container handling cell. While suspended, the waste package will be decontaminated as needed. A reusable railcar will be pushed under the waste package from the underground transporter. The waste package will be lowered onto the railcar and the loaded railcar pulled back into the transporter. The shielded transporter will leave the waste handling building to complete the waste packaging operations. All operations in the waste package transporter loading cell will be conducted by remote control. This cell will include:

- A 100-ton capacity horizontal bridge crane
- Decontamination and survey equipment
- Two waste package transporter loading cell manipulators
- A horizontal transfer cart and cameras
- Shield walls, shielded doors and windows
- Cameras.

Uncanistered Spent Nuclear Fuel Waste Packages

21-PWR UNCANISTERED FUEL WASTE PACKAGE ASSEMBLY

Note: Information in () refers to the type of material used.

44-BWR UNCANISTERED FUEL WASTE PACKAGE ASSEMBLY

SNF DISP. PPT. 121.FDD

Uncanistered Spent Nuclear Fuel Waste Packages

The spent nuclear fuel waste packages will be designed to support the confinement and isolation of bare spent nuclear fuel assemblies in the potential geologic repository. These waste packages will be loaded with spent nuclear fuel assemblies from either boiling water reactors (BWRs) or pressurized water reactors (PWRs).

Basic designs for two BWR and three PWR waste packages will be developed for long-term confinement of the commercial spent nuclear fuel; the dimensions for each are shown in the table below. Absorber plates and rods may also be added to improve criticality control for a total of three BWR and five PWR waste package designs.

The corrosion-resistant inner barrier will be a nickel based alloy, ASTM B575 Alloy N06022 (Alloy 22).

WP Type	Outer Diameter	Outer Length	Outer Barrier Thickness	Inner Barrier Thickness	Unloaded Mass (kg)	Loaded Mass (kg)
21-PWR - no absorber	1.664 m	5.335 m	0.10 m	0.02 m	35,000	52,000
21-PWR - absorber plates	1.664 m	5.335 m	0.10 m	0.02 m	35,000	52,000
21-PWR - absorber rods	1.634 m	5.335 m	0.10 m	0.02 m	35,000	52,000
12-PWR - no absorber	1.320 m	5.335 m	0.10 m	0.02 m	25,000	35,000
12-PWR - absorber plates - long	1.350 m	5.871 m	0.10 m	0.02 m	29,000	39,000
44-BWR - no absorber	1.604 m	5.335 m	0.10 m	0.02 m	33,000	47,000
44-BWR - absorber plates	1.604 m	5.335 m	0.10 m	0.02 m	33,000	47,000
24-BWR - thick absorber plates	1.338 m	5.335 m	0.10 m	0.02 m	28,000	36,000

The outer barrier will be of carbon steel (A516). In addition, the cladding around the commercial spent nuclear fuel will improve overall containment performance.

An internal basket will hold the spent nuclear fuel assemblies. The basket will provide criticality control, structural support, and heat conduction paths to dissipate heat generated by the spent nuclear fuel.

Whether the 21-PWR waste package (containing 21 assemblies) will use a basket with or without neutron-absorber plates depends on the reactivity of the spent nuclear fuel. Neutron-absorber rods will also be inserted in PWR fuel assemblies as needed for criticality control. The 12-PWR waste package will come in two lengths. The shorter (5.34 m) waste package can be used without a neutron absorber; the longer waste package (5.87 m) can be used with neutron-absorber plates for spent nuclear fuel assemblies that are significantly longer than other PWR assemblies. The 44-BWR waste package can be used with or without neutron-absorber plates. The 24-BWR waste package will use thicker neutron-absorber plates to control criticality.

The 24-BWR and 12-PWR waste packages have been designed to contain spent nuclear fuel that has a higher than average heat generation rate and still maintain the required maximum heat-output of 18 kilowatts per package.

Canistered Spent Nuclear Fuel and Co-Disposal Waste Packages

CANISTERED SNF-WASTE PACKAGE ASSEMBLY

Note: Information in () refers to the type of material used.

DHLW/DOE SNF CO-DISPOSAL WASTE PACKAGE

CANDISP 2.CDR.121.RDD/01-14-99

DHLW = defense high-level waste

Canistered Spent Nuclear Fuel and Co-Disposal Waste Packages

Some of the waste forms may arrive at the repository already in canisters suitable for long-term direct disposal. This canistered waste includes commercial spent nuclear fuel, Naval fuel, DOE spent nuclear fuel, vitrified high-level waste, and immobilized plutonium. These canisters will be in waste packages that will support their containment and isolation in the engineered barrier of the potential repository. Some of the designs described in this section, particularly those containing many elements, are preliminary because of unresolved long-term criticality issues.

Canisters containing a single spent nuclear fuel element will be placed into the “uncanistered” spent nuclear fuel waste packages because they are interchangeable with the bare spent nuclear fuel assemblies. Canisters containing several elements of commercial spent nuclear fuel (multi-element) will be placed in a disposal container to form a “canistered spent nuclear fuel” waste package for direct disposal. Acceptable multi-element canister designs are still under development.

The co-disposal waste package for DOE spent nuclear fuel and high-level waste canisters will hold five high-level waste disposable canisters. A DOE spent nuclear fuel canister will be inserted in the middle of the high-level waste canisters. There are three waste package designs for canisters containing high-level waste, two of which allow the disposal of a canister of DOE spent nuclear fuel in the middle.

For the DOE spent nuclear fuel that will not be placed in the middle of a high-level waste package, an additional waste package design will be required. The waste package being developed for N-reactor fuel will hold four specially designed canisters referred to as multi-canister overpacks.

Because there will be two canister sizes (one short and one long) for the Naval spent nuclear fuel, there will be two waste package designs based on the length of the canisters. The canisters will fit one to a waste package as will the multi-element canistered, commercial spent nuclear fuel.

Waste Package Type	Outer Diameter	Outer Length	Outer Barrier Thickness	Inner Barrier Thickness	Unloaded Mass (kg)	Loaded Mass (kg)
Commercial canistered fuel-24 BWR	1.540 m	5.657 m	0.10 m	0.02 m	27,000	46,000
Commercial canistered fuel-44 BWR	1.946 m	5.657 m	0.10 m	0.02 m	35,000	69,000
5-HLW canister	1.970 m	3.790 m	0.10 m	0.02 m	26,000	37,000
5-HLW/DOE SNF	1.970 m	3.790 m	0.10 m	0.02 m	25,000	38,000
5-HLW/DOE SNF - long	1.997 m	5.367 m	0.10 m	0.02 m	35,000	58,000
Naval fuel - short	1.959 m	5.530 m	0.10 m	0.02 m	35,000	79,000
Naval fuel - long	1.959 m	6.165 m	0.10 m	0.02 m	38,000	83,000
4-multi canister overpack	1.841 m	4.985 m	0.10 m	0.02 m	29,000	65,000

Waste Emplacement System

Waste Emplacement System

The Waste Emplacement System will transport the loaded and sealed **waste packages** from the waste handling building to the emplacement area where they will be put on supports along the centerline of the emplacement drift.

Two manually controlled **transport locomotives**, with radiation shielding to protect the operator, will move the shielded transporter containing the waste package down the north ramp and the main drifts and leave it. Operators will then open the **drift isolation doors** remotely. One remote-controlled locomotive will back the **waste package transporter** against the transfer dock behind the doors at the emplacement drift entrance. The **reversible rail car** containing the waste package will then be rolled out of the transporter onto the transfer dock. Isolation doors will be closed after the transporter is pulled away.

The **emplacement gantry**, already positioned in the **drift**, will be moved into position over the waste package. The gantry will lift the waste package off the transfer railcar and carry the waste package through the drift to its final location. The gantry will lower the waste package onto its supports and return to the emplacement drift entrance to await the arrival of another waste package.

Four major pieces of equipment will be used to emplace waste packages.

- (1) Two transport locomotives with the following features:
 - Electrically powered overhead trolley wire system
 - Controls for both manual and remote operations

- Approximately 340 horsepower each
 - Weight of approximately 45 tons each.
- (2) A waste package transporter with the following features:
 - Internal reusable rail car
 - Empty weight of 168 tons
 - Loaded weight of approximately 300 tons (with heaviest waste package)
 - Integrated, remote-controlled, loading/unloading mechanism to accept and deploy waste packages on a transfer railcar
 - Radiation shielding of carbon steel and borated polyethylene for gamma/neutron shielding, sandwiched between inner and outer layers of stainless steel
 - Remotely operated doors with manual override
 - Redundant, fail-safe braking system with control from transport locomotives and surface control system.
 - (3) An emplacement gantry with the following features:
 - Electrically powered through a third rail system
 - Rail mounted with driven wheels on each corner and redundant critical systems
 - Remote-controlled functions
 - Capable of handling full range of waste package sizes and weights.
 - (4) A gantry carrier with the following functions and features:
 - Capable of transferring gantry to all emplacement drifts
 - Can be moved by transfer locomotive
 - Powered third rail for gantry transfer onto carrier.

Monitoring Phase

Monitoring Phase

During this phase, monitoring and maintenance intensify. The current reference design is based on a 150-year pre-closure life, which includes 5-6 years of initial construction, 100 years of repository operations and performance confirmation testing, 34 years for retrieval (if needed), and 10 years for closure. In addition, the design will allow for reasonable maintenance that can extend the life of the repository to 300 years, which will provide flexibility for future decision-makers.

Specific facilities and equipment will be maintained to support monitoring and data analysis. Facilities and equipment needed to respond to emergencies will be maintained.

During this phase, permanently installed sensors will monitor waste packages, drifts, and the surrounding rock to provide the data for analysis. These subsurface sensors will be accessible for calibration and maintenance from observation drifts that do not contain waste packages and can be safely entered by workers. A remote-controlled inspection gantry will investigate conditions in the emplacement drifts to limit risk to workers from heat and radiation from the waste packages. If a decision is made to retrieve the waste packages during the 100-year retrievability period or at its end, the emplacement drift will be cooled down using forced ventilation and the waste packages can then be removed. It is possible to accomplish this in 34 years, allowing a 10-year planning period and a 24-year retrieval period.

Remote inspection of the emplacement drift to identify potential obstructions may be required. Removing one waste package may require the shifting or removal of other packages.

Closure Phase

Closure Phase

After emplacement of the nuclear waste inventory has been completed and the monitoring program has shown that the repository will perform as expected, it will be closed. Closure cannot proceed unless the NRC has issued a license amendment to close the repository. Closure will require the following activities:

- Sealing all openings to the surface
- Dismantling the surface facilities
- Restoring the surface area
- Protecting the repository from unauthorized intrusion.

Sealing all repository openings will discourage human intrusion and retard the flow of water and gas into and out of the closed facility through the drift openings. Sealing will include:

- Removing all nonpermanent equipment from the subsurface facility
- Installing seals in all engineered openings to the surface, including shafts, ramps, and any boreholes that have been drilled to the repository level.

During closure, surface facilities will be decontaminated, decommissioned, and removed. This will restore the surface site to as near its original condition as is reasonable and feasible. To facilitate this process, surface facilities will be designed to simplify final decontamination and decommissioning. During this time, the waste treatment building will treat and package solid and liquid low-level waste for transport to low-level waste disposal sites.

Detailed records and information on the repository will be distributed to government organizations. Permanent monuments will be placed at the closed repository to alert future generations that radioactive waste is buried there.

Postclosure Performance

V. POSTCLOSURE PERFORMANCE

The primary objective of the potential repository at the Yucca Mountain Site is to limit radiation levels and exposures, in both restricted and unrestricted areas, and releases of radioactive materials to unrestricted areas. After permanent closure, the geologic repository is required to limit the expected annual dose to the average member of the critical group. The combination of natural and engineered barriers will ensure that annual doses to persons on the surface are well below regulatory standards.

The design, therefore, addresses these key attributes of the repository system important to postclosure performance:

- Limited water contacting waste packages
- Long waste package lifetime
- Slow rate of release of radionuclides from breached waste packages.
- Radionuclide concentration reduction during transport from the waste package.

The mountain itself provides a thick, unsaturated zone where waste can be placed deep below the surface, yet well above the water table. This protects the waste packages from changes in conditions at the surface but still keeps them well away from the saturated zone. Site characterization studies have shown that the repository will not flood, the water table will remain well below the repository, the rocks above the repository will not erode away, the seismic effects will be minor, and the likelihood of volcanoes is exceedingly small.

The central focus for the next two and one-half years will be to evaluate the performance and longevity of the engineered barriers under consideration. The design will not rely on a single barrier but will rely on defense-in-depth (i.e., multiple barriers). These multiple barriers will mitigate uncertainties in conditions, processes, and events so that failure of any one barrier does not cause failure of the entire system. Evaluations indicate that the containment barriers will last tens of thousands of years and perhaps hundreds of thousands of years. Work in the next few years will focus on testing the performance and stability of the individual barrier materials and designs and in evaluating specific combinations of barriers from the viewpoint of cost and confidence in postclosure system performance.

Engineered Barrier System

Engineered Barrier System

The Engineered Barrier System will support the key geologic repository mission by containing the waste for long periods, limiting radionuclide release to the natural barrier, controlling external effects on the engineered system, after the waste package is breached, and providing **waste package support** and spacing. The Engineered Barrier System will consist of the **waste packages**, waste package support hardware, and performance enhancing barriers. Alternative designs for the Engineered Barrier System are presented in Section VI, Design Options.

Heat produced by the spent nuclear fuel in the waste packages will keep the rock temperature around the drift above the boiling point of water for hundreds to several thousands of years (depending on the kind of waste package and the thermal-hydrological properties of the nearby rock). For most waste package locations, this will keep the drifts dry and at low humidity, which will reduce the corrosion rate of the waste packages. The design goals for the Engineered Barrier System are to prevent breaching of the waste packages for 3,000 years and to prevent seepage water from contacting the waste for at least 10,000 years. (Breaching of the waste package is defined as an opening through the wall of the waste package that allows transport of radionuclides.) See the discussion of disposal containers for design characteristics of the waste packages.

The waste package support assembly will consist of a **pier** and a **waste package support**. The pier and support will hold the waste package off the drift floor to allow heat to radiate away more evenly. The waste package support assembly is modular and allows both flexibility in the waste package placement in the drifts and replacement of individual components in the event the support structure is damaged.

The **invert segments** (the floor of the emplacement drift) will be made out of precast concrete. The main purpose of the invert is to provide a means to transport and emplace the waste packages, support the waste packages, and provide drainage away from the waste packages of any seepage water.

Commercial spent nuclear fuel cladding contributes to repository performance. The cladding is a thin metal tube which encases the fuel-pellet waste form and delays any contact with water, thus retarding dissolution of the waste and subsequent release of radionuclides. The thermal design of the waste package protects the integrity of the cladding. The cladding is designed and fabricated to perform in the harsh reactor environment where pressures can exceed 2000 lbs./in² and fuel cladding temperatures can reach 700 °F.

Performance Confirmation System

Performance confirmation will include gathering data on the waste packages, drifts, and mountain. The data will be evaluated to determine if the repository is performing as expected.

Performance Confirmation System

The Performance Confirmation System acquires data to verify that subsurface conditions during construction, waste emplacement operations, and conditions during the monitoring period are within predicted limits. It will also acquire data to verify that the natural and engineered systems and components are functioning as intended. The previously constructed Exploratory Studies Facility, test alcoves, monitoring and testing equipment, data acquisition system, surface-based monitoring and test equipment, and laboratory testing equipment will be replaced, modified, or used as is. This system will operate from site characterization to closure.

During the site characterization period, information will be developed on subsurface conditions and natural systems. Any changes from previous data resulting from site characterization and construction activities will also be monitored and analyzed. Performance confirmation activities will require the following equipment and facilities:

- Three to five permanent observation or monitoring drifts with instrumented boreholes
- A monitoring system for emplacement drift ventilation

- Test alcoves in non-emplacement subsurface areas
- A remotely operated gantry inspection system to monitor waste packages
- A multi-purpose performance confirmation (Waste Package Remediation System) hot cell in the waste handling building with:
 - Approximately 2,000 square feet of area by 36 feet high
 - Concrete shield walls lined with stainless steel
 - Master-slave and electro-mechanical manipulators
 - Heavy duty cart
 - In-cell crane
- An administrative support area for performance confirmation
- A data acquisition system
- Surface-based monitoring and testing equipment
- Laboratory testing equipment.

Engineered Barrier System Viability Assessment Design Options

Schematic Not To Scale

VI. DESIGN OPTIONS

Engineered Barrier System Viability Assessment Design Options

In addition to the features of the Engineered Barrier System described previously, three performance-enhancing design options are being evaluated as part of viability assessment. These design options include using backfill, ceramic coating, and/or drip shields.

If the backfill option is used, backfill will be placed just before closure but after the retrievability period. The backfill is currently being studied and may consist of a dry granular material, possibly tuff excavated from the repository or quartz sand. This backfill material will be selected to ensure that it doesn't accelerate corrosion of the waste packages and that it will not lessen the waste isolation capabilities of the natural barrier.

If the ceramic coating option is used, it will be placed on the outside of the waste package. The ceramic coating will be designed to minimize degradation of the waste package. If a ceramic coating is used, backfill will also protect the ceramic coating from rock fall in the emplacement drift. While the waste packages in the reference design include a corrosion allowance barrier and a corrosion resistant barrier, an additional ceramic barrier may offer greater defense-in-depth.

Long-life drip shields may be used to divert any dripping water that may enter the drifts. Whether to use drip shields will be determined after evaluating their effectiveness for reducing corrosion rates and for delaying or reducing radionuclide release to the accessible environment.

The selection process used to evaluate these three options will be based on the scenarios predicted for the waste isolation period (considering temperatures, humidity, water flow, chemistry, and mechanical loads) as a function of time and location. The functions of these options for the engineered barrier components then will be evaluated for their capability to delay breach of the waste package, and slow the release of radioactive materials from the waste package.

These design options are important in selecting the system of engineered barriers to isolate and contain potentially mobile radionuclides in the repository. Design options will be incorporated, if necessary, to ensure that the system of natural and engineered barriers provides several layers of safety to limit radionuclide exposure to water and prevent transport to the accessible environment.

The current analyses of the design options are preliminary and their feasibility and longevity have not yet been determined. Those options will be evaluated as part of a comprehensive evaluation of design options and alternatives leading to recommendation of a design in 1999. In addition to design margin and defense-in-depth, the design alternatives evaluation will address other objectives including flexibility of design, schedule, cost, and both preclosure and postclosure safety.