A CONCEPTUAL DESIGN FOR A NUCLEAR WASTE REPOSITORY AT THE YUCCA MOUNTAIN SITE* SAND88-0001C

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ABSTRACT

The Yucca Mountain Project recently completed a conceptual design for a nuclear waste repository at the Yucca Mountain site. This conceptual design provides a reference configuration to be used during the site characterization program to evaluate the suitability of that site for a repository. The surface and underground facilities were designed for the unique topographic, structural, and hydrologic setting at Yucca Mountain. This unique setting allows inclined ramps to be used for access to the underground facilities and allows the repository to be located in the unsaturated zone above the water table. Subsequent design activities will provide for more detailed specification of design features and operational modes for the repository facilities.

INTRODUCTION

The Nuclear Waste Policy Act (NWPA) of 1982(1) required the U.S. Department of Energy (DOE) to select candidate sites for nuclear waste repositories to dispose of the waste from the nation's nuclear power reactors. In 1985, President Reagan determined that the high-level waste from defense program activities will also be disposed of in these repositories(2). One of the sites selected in 1986 for characterization for the first repository was the Yucca Mountain site in Nevada(3). More recently, the NWPA was amended to select the Yucca Mountain site as the only site to be characterized(4).

The NWPA required a site characterization plan to be developed for each site to be characterized and, in addition, required a conceptual design for a repository at that site. Consequently, the Yucca Mountain Project (YMP) recently completed a conceptual design for a repository at the Yucca Mountain site(5). This conceptual design supports the site characterization program by defining a reference description of the repository surface and underground facilities. This reference description provides a basis for identifying design-related issues and one basis for determining the appropriate site characterization activities to obtain needed information about the site.

Site characterization will begin soon at the Yucca Mountain site. It will consist of a systematic evaluation of the geologic, hydrologic, and other physical features of the site to determine if a repository constructed at the site would adequately provide containment and long-term isolation of the radioactive material in the nuclear waste. If the site is deemed suitable for the construction of a repository, a license application will be submitted to the Nuclear Regulatory Commission (NRC), which will then evaluate the information obtained during site characterization and determine whether to grant a construction authorization. If Yucca Mountain is designated as the site for a license application for the final repository, a final design will be prepared as the basis for construction.

A conceptual design differs from more detailed designs in that it emphasizes the identification of basic features and concepts that will perform the required repository functions and, at the same time, provide a safe operating system. Further, it allows a preliminary description of the system so that estimates of cost and schedules can be made and identifies those important features that need further evaluation.

This paper provides a summary of the conceptual design performed for the Yucca Mountain site. A brief review of the basis for the design is provided, then a description of the surface and underground facilities is presented, and finally some important aspects of the design in relation to the performance of the system are given.

BASIS FOR THE DESIGN

The design of the nuclear waste repository must consider two important factors-- the site and its physical features and the waste that will be received at the facility. The Yucca Mountain site provides some unique characteristics that contributed to the current conceptual design. The site, located about 85 mi (by air) northwest of Las Vegas, NV, is in an extremely remote, sparsely populated area. Yucca Mountain is a series of bedded deposits of volcanic tuff rocks deposited about 13 million years ago. Subsequent regional deformation produced uplift and tilting of large structural blocks that formed the mountain and adjacent valleys.

This deformation and subsequent erosion resulted in the current topography of the site. The volcanic rock within the mountain is in several stratigraphic units of both welded and nonwelded tuff. The water table is sufficiently deep (between 500 and 800 m below the surface, within the subsurface operations area shown in Fig. 1) that the

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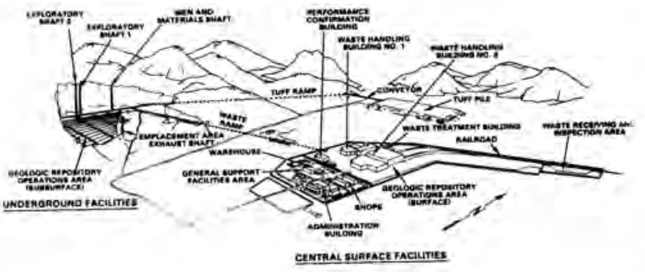

Fig. 1. Conceptual Configuration of YMP Repository Facilities to be Located at the Yucca Mountain Site.

repository will be located entirely in the unsaturated rock above the water table(6).

The site is adjacent to the Nevada Test Site where the nation's underground nuclear testing activities are performed. One of the basic requirements for the repository is that it does not impair the ability to perform such testing and that the testing activity does not impact the safety of repository operation.

The topographic features at the site restrict the potential locations of the surface facilities, resulting in a conceptual design that places the surface facilities about a mile to the east of the mountain, where the slope of the surface is more gentle (Fig. 1). This surface facility location is actually a desirable feature because the low elevation at that location allows access to the underground facilities by mined ramps. The ability to use ramp access and tunnel-boring machines to develop many of the underground facilities provides significant operational and construction advantages.

The amount and characteristics of the wastes to be received at the repository will determine, in part, the size and complexity of the facility. The present design basis provides for receiving both spent fuel from civilian power reactors and high-level waste (HLW) from defense operations. The spent fuel could come directly from the reactors or from a monitored retrievable storage (MRS) facility, which would be an intermediate facility for collecting and packaging spent fuel from numerous reactors and sending consolidated shipments to the repository(7). The likely location for an MRS is in the eastern U.S.; thus spent fuel from reactors in the western U.S. would still come directly to the repository if the repository is actually built at Yucca Mountain.

HLW from U.S. defense programs would be the result of reprocessing operations in which the waste products are encapsulated in a stable form. This waste could come from defense installations at the Savannah River Plant in South Carolina, the Hanford reservation in Washington, and a similar facility in Idaho. A facility is being constructed at Savannah River to produce vitrified HLW. The glass waste form from this facility serves as the reference defense waste form for repository design. It is expected that HLW from other defense facilities will be similar. A small amount of HLW is expected from the West Valley facility in New York. These wastes are a result of initial reprocessing attempts in this country and are similar in form to the defense wastes.

The amount of waste to be received by the first repository was established by the NWPA. The design basis for the Yucca Mountain conceptual design is a total capacity of 70,000 metric tons uranium (MTU) equivalent. This total includes spent fuel from boiling water reactors (BWRs) and pressurized water reactors (PWRs), the defense high-level wastes (DHLW), and the West Valley products. The allocation of repository capacity to these types of wastes is shown in Fig. 2. The operations in the repository are strongly influenced not only by the capacity of the facility, but also by the number of containers of wastes to be emplaced. The number of containers of DHLW is determined by the desired product from the vitrification facility. The number of containers of spent fuel is determined by the amount of thermal power and radioactivity that can be placed in each container, consistent with the operational and waste isolation requirements of the repository. The respective number of containers for each of the major waste forms is also shown in Fig. 2.

The current repository design provides a phased waste emplacement schedule. This schedule results in two distinct waste-handling facilities on the surface. A smaller facility to be used for initial operations can accommodate a receipt rate of 400 MTU/yr for the first three years of operation. A larger facility will be developed for full-scale operations.

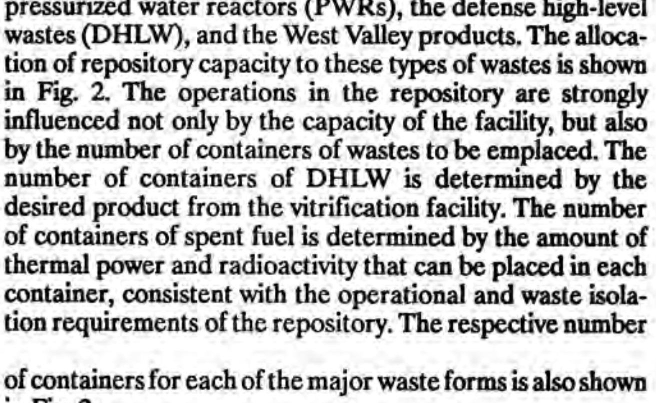

Fig. 2. Summary of the Design Basis Waste Parameters.

The acceptance rate will increase to 900 MTU/yr in the fourth year of operation, progressing to 1800 MTU/yr in the fifth year, and finally reaching the design capacity of 3400 MTU/yr in the sixth year of repository operation.

Waste could arrive at the repository in either truck or rail casks. The reference design assumes that 70% will arrive in truck casks and 30% in rail casks, but it must be sufficiently flexible that 80% could be received in rail casks and 20% in truck casks.

SURFACE FACILITIES AND WASTE-HANDLING OPERATIONS

The surface facilities of a repository primarily provide for receipt of the waste in the shipping cask, unloading the waste from the cask, and packaging the waste for transport to underground emplacement locations. The conceptual design provides for two waste-handling buildings for initial and final operations.

The larger waste-handling building (Fig. 3) will provide a number of entry points (eight in the design shown) devoted either to truck or rail casks. These entry points consist of airlocks and receiving bays where the casks are lifted from the delivery vehicle and transferred to an unloading cell. In the unloading cell, the spent fuel or HLW is unloaded from the casks by an overhead crane. The spent fuel is transferred to a processing cell for consolidation of fuel rods and then transferred to a packaging hot cell; the HLW is transferred directly to a packaging hot cell. In the packaging hot cell, spent fuel rods or an HLW canister are sealed in a container designed to meet the long-term containment requirements specified by the NRC. These containers are then moved to the underground facility by a transporter vehicle.

During full-scale operations, a large quantity of material will be handled by the surface facility. The values shown in Table I are consistent with the current canister design for the Yucca Mountain site and assume that the spent fuel is consolidated at the repository.

Assuming material flow rates shown in Table I and a 250-day work year, the surface facility must accept nine truck casks during an average working day, with a rail cask arriving every other day. Further, provisions must be made each day to unload approximately 40 spent fuel assemblies and weld 8 containers for disposal. This throughput requirement represents a major challenge for remote-handling technology, especially if fuel consolidation is performed at the repository. Consolidation will be the most complex of the operations performed at the repository. A consolidation facility, as incorporated into a repository at the Yucca Mountain site, is shown in Fig. 4. It is this facility that will require the most effort to design, build, and operate at these receipt rates and under the stringent operational and safety requirements placed on the repository.

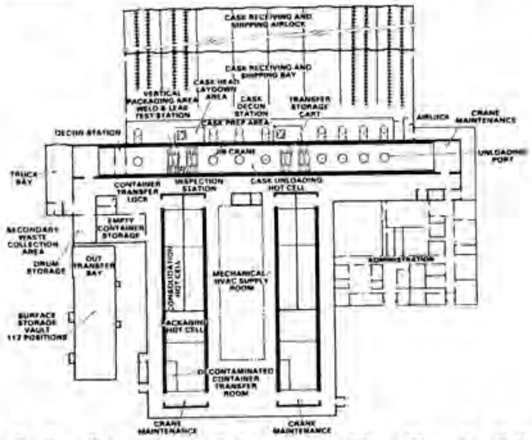

Fig. 3. Configuration of the Waste-Handling Building in Plan View.

TABLE I
Typical Material Flow at the Repository

Vehicles	Quantity
Rail cars	139/yr
Trucks	2282/yr
Spent Fuel Assemblies	
PWRm	3901/yr
BWR	6545/yr
Disposal Containers	
PWR	715/yr
BWR	436/yr
HLW	800/yr

UNDERGROUND FACILITIES AND WASTE EMPLACEMENT

After the waste is processed in the surface facility, it will be loaded into a transporter. The transporter will move down the waste ramp to the underground facility where the waste container will be placed into holes drilled in the floor or in the sides of the underground rooms.

The current conceptual design contains two different options for waste emplacement--vertical and horizontal. In the vertical (reference design) case, single waste containers are placed in individual boreholes in the floor of the underground drifts. In the horizontal option, several waste containers are placed in horizontal boreholes drilled in the sides of the drifts. The underground configurations for vertical and horizontal emplacement are shown in Figs. 5 and 6, respectively.

In both configurations, the amount of underground area needed for the 70,000 MTU equivalent quantity of waste is approximately the same (less than 50 acres difference out of about 1420 acres). This area is determined primarily by establishing how much waste can be emplaced per unit of area, i.e., the emplacement density, although

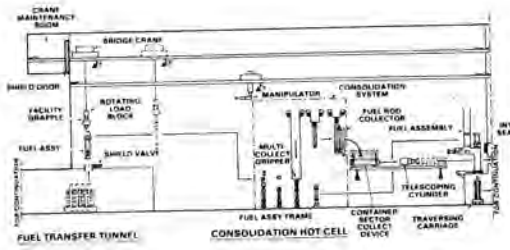

Fig. 4. Conceptual Spent Fuel Consolidation Operations.

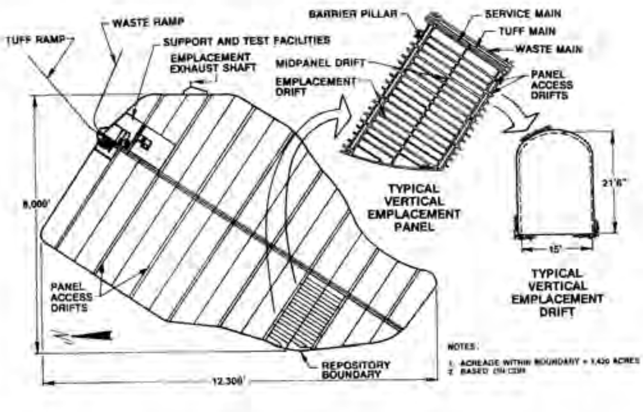

Fig. 5. Conceptual Design of the Underground Facilities for the Vertical Waste Emplacement Mode.

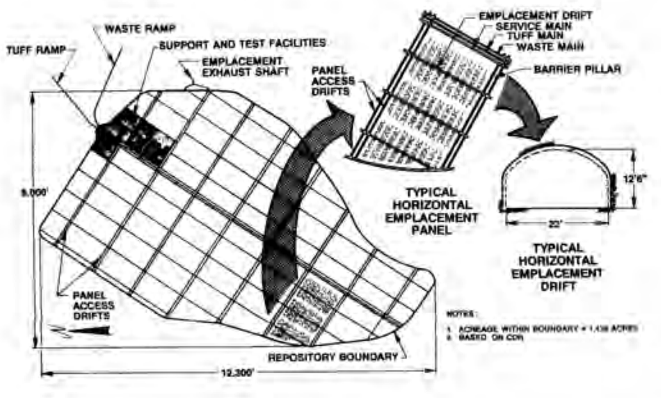

Fig. 6. Conceptual Design of the Underground Facilities for the Horizontal Waste Emplacement Mode.

space is also provided for shops, test and support facilities, and access drifts. The primary factors used in establishing the emplacement density were (1) the thermal power of the waste (considering waste age and burnup characteristics), (2) peak temperature constraints for fuel rod cladding, (3) near-field temperature constraints in the drifts, and (4) far-field constraints on surface temperature changes and surface movement. The current design is based on an average thermal power density of 57 kW/acre within an emplacement panel and a reference thermal power of approximately 1 kW/MTU for spent fuel (assuming the fuel is emplaced at ten years out of the reactor) and 0.4 kW/MTU for HLW.

The extent of the underground facilities is determined, in part, by the structural setting at the Yucca Mountain site. A primary area of approximately 1690 usable acres is planned for the repository; it is bounded horizontally by structural features and vertically by the requirement to maintain a minimum of 200 m of overburden within the irregular topography at the site. The slope of the drifts (% grade) is determined by the desire to maintain the repository openings within the unsaturated Topopah Spring Member of the Paintbrush Tuff and within the vertical and horizontal constraints established by this topography and structure. Additional adjacent areas for potential waste emplacement have been identified. Substantial additional information regarding the configuration and area available for waste disposal will be obtained during the characterization activities at the site. The lateral extent of the underground openings is about 1.5 mi x 2 mi. More than 100 mi of drifts will be developed in the area to support mining, mined rock removal, waste emplacement and retrieval, ventilation, underground shops, training, and both site characterization and performance confirmation testing. The extraction ratio in the emplacement panels is about 16% for the vertical emplacement option and 5% for the horizontal option. The drifts will range in size from 16 to 25 ft in width and from 13 to 22 ft in height, depending upon function.

The site-specific conceptual design formed the basis for identifying the design- related data needed from the Yucca Mountain site. Future design activities can be focused upon integrating new site information into the configuration decisions, design requirements, and repository performance analyses.

IMPACT OF REPOSITORY DEVELOPMENT ON CONTAINMENT AND ISOLATION

The fundamental purpose of a repository is to isolate the radioactive material in the nuclear waste from people and the accessible environment. The Yucca Mountain site provides the basic conditions for that isolation. Repository facilities must be designed to limit the impact of construction, operation, closure, and decommissioning on the isolation characteristics of the site.

With the current design, it is anticipated that potential escape of radioactive material from the repository would result from waste interaction with and transport by groundwater(6). A simple depiction of the Yucca Mountain site is shown in Fig. 7. In the undisturbed case, groundwater in the unsaturated zone is held in the partially filled

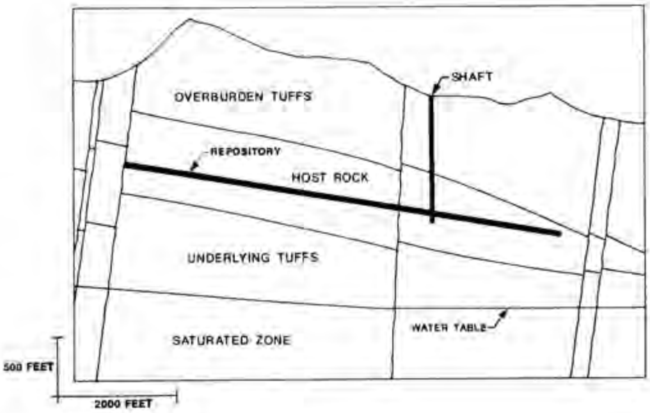

Fig. 7. A Simple Depiction of the Stratigraphy and Structure of the Yucca Mountain Site.

microscopic pores of the tuff rocks. Small amounts of water resulting from precipitation at the surface could infiltrate the mountain, producing a net flux that is estimated to be less than 1 mm/yr, directed downward toward the water table. Any analysis of the performance of this system must consider the impact of the construction of the underground drifts, shafts, and ramps on the transport of radioactive material.

The conceptual design for a repository at Yucca Mountain incorporated numerous features that will serve to limit the amount of water that may contact the waste. These features include (1) locating the repository a substantial distance (greater than about 175 m) above the water table, (2) locating the repository at least 200 m below the surface to eliminate concerns related to erosion, (3) locating the entrances to the shafts and ramps above local flood plains, and (4) establishing the slope of repository drifts so that any drainage of water would generally be directed away from the emplaced waste. Additionally, shaft depths are generally limited to just below the repository depth so that they cannot become pathways for radionuclide migration downward from the repository. Construction operations will be controlled to limit the quantity of water introduced into the unsaturated formation by construction and borehole drilling operations. Repository drifts will be located at least 15 m from exploratory boreholes to assure that containment and isolation of the waste are not impacted. Finally, the concrete liners in the shafts are being designed so that they can be removed, if necessary, when seals are placed in the shafts during decommissioning.

The impacts on the hydrologic system of the heat produced by the waste must also be evaluated. The heat from the waste will cause the rock near the waste packages to increase in temperature, which will induce thermal stresses in the rock. The temperature of the rock and its effect on the presence of water that could react with the waste package will ultimately influence how long the container material will remain intact and how much radioactive material is available for release into the local water contained in the rocks. In the unsaturated zone, free water is found principally in the small pore spaces in the rock and is not generally available to react with the waste container. An increase in temperature will serve to further dry out the region around the waste packages because the pressure is essentially atmospheric. Thus the potential of the waste package interacting with the groundwater is even further reduced.

The thermal stresses induced in the rock could influence the stability of the rooms during the repository operating period. Potential long-term impacts of the stresses include the creation of fracture systems that could modify the hydrologic flow system. The unsaturated zone provides unique features that could limit the impact of induced fractures. Strong capillary forces tend to induce the water to remain in the smaller pores rather than flow in fractures where it could be available for contact with waste containers. Therefore the creation of new fractures or the opening of existing fractures is expected to have little impact on the flow of water.

Nevertheless, the region of rock within a few meters of the waste was assumed to be disturbed and will not be relied upon for isolation of waste from the accessible environment. In addition, the conceptual design of the repository incorporated features that will limit the amount of fracturing that could occur. These features include limiting the amount of rock that will be removed from the underground openings (i.e., limited extraction ratios), backfilling the underground openings with rock when the repository is closed, and using controlled blasting techniques or tunnel boring machines to limit damage associated with excavation of the rock.

SUMMARY

A conceptual design was developed for a nuclear waste repository at the Yucca Mountain site. This conceptual design is based on available information about the site and on anticipated characteristics of the wastes that would be emplaced at the site. The conceptual design provides a reference description of the surface and underground facilities that, in turn, provides a basis for defining specific site information needed to complete subsequent design phases and to assess the ability of the total mined geologic disposal system to meet the regulatory requirements for containment and isolation of the radioactive materials in the nuclear waste. Site characterization at Yucca Mountain is scheduled to begin soon.

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