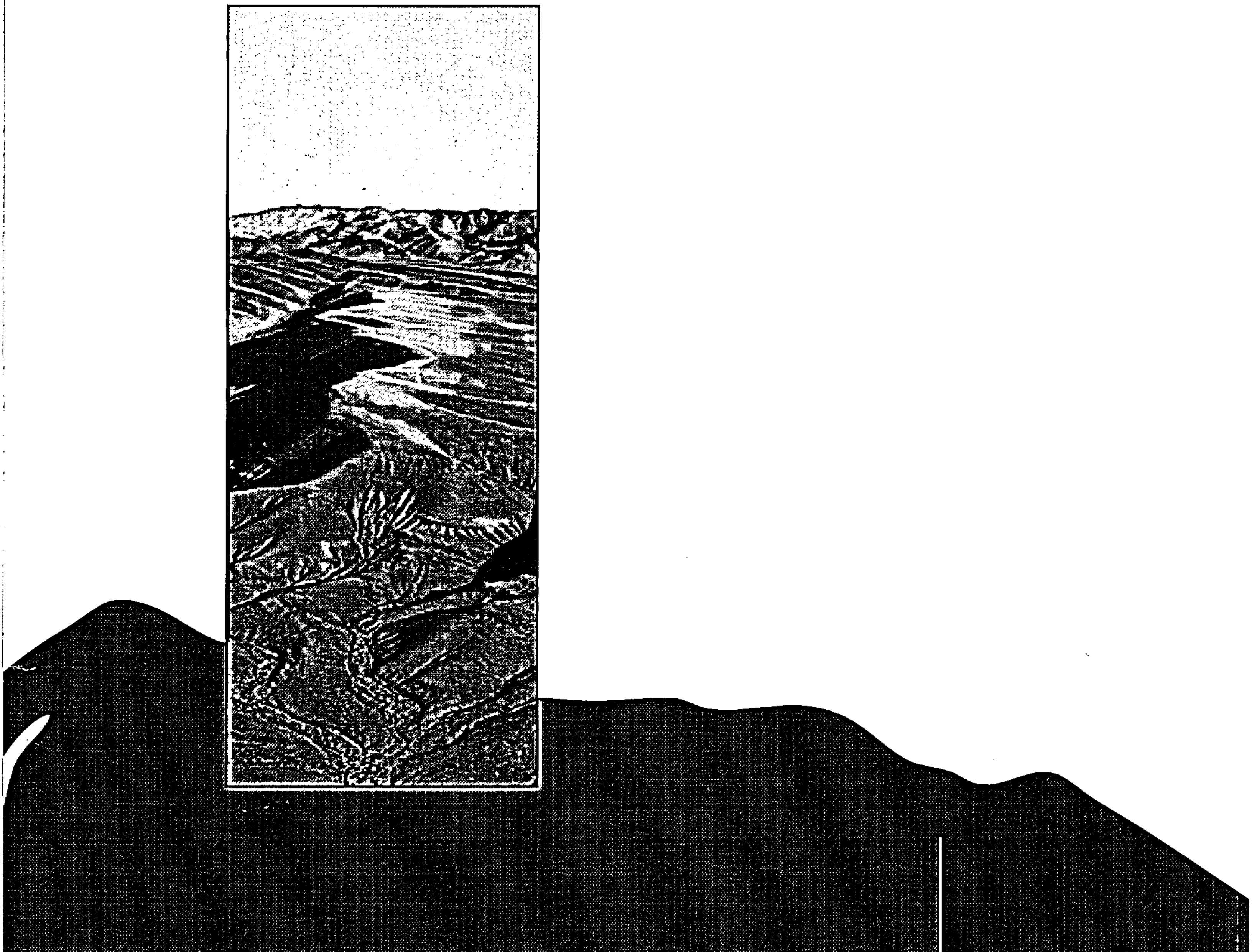

Viability Assessment of a Repository at Yucca Mountain

Overview

U.S. Department of Energy

Office of Civilian Radioactive Waste Management

DOE/RW-0508

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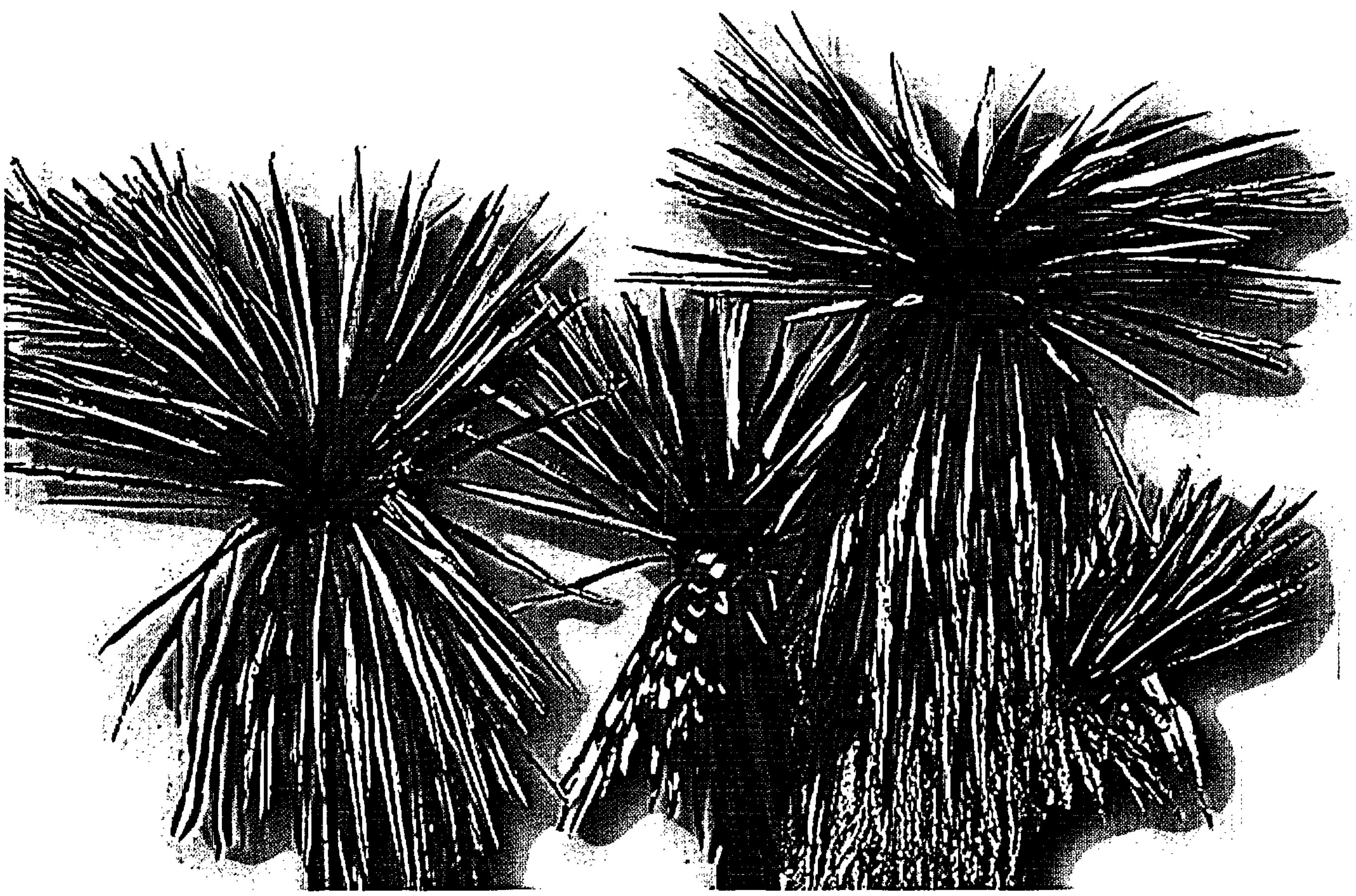
December 1998



U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office

This publication was produced by the U.S. Department of Energy
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Contents

The Viability Assessment

The U.S. Department of Energy (DOE) has been studying a site at Yucca Mountain, Nevada, for more than 15 years to determine whether it is a suitable place to build a geologic repository for the nation's commercial and defense spent nuclear fuel and high-level radioactive waste. This overview presents the results of DOE's study to date.

In 1996, DOE announced that it would complete in 1998 a viability assessment of the Yucca Mountain site that would describe the following:

- The preliminary design concept for the critical elements of a repository and waste package
- A total system performance assessment, based on the design concept and the scientific data and analyses available by 1998, that describes the probable behavior of a repository in the Yucca Mountain geologic setting
- A plan and cost estimate for the remaining work required to complete and submit a license application to the Nuclear Regulatory Commission
- An estimate of the costs to construct and operate a repository in accordance with the design concept

In the 1997 Appropriations Act,[1] Congress required DOE to prepare the viability assessment.

The purpose of the viability assessment is to provide Congress, the President, and the public with information on the progress of the Yucca Mountain Site Characterization Project. The assessment also identifies the critical issues that need to be addressed before a decision can be made by the Secretary of Energy on whether to recommend the Yucca Mountain site for a repository.

This overview of the *Viability Assessment of a Repository at Yucca Mountain* describes the nuclear waste problem and explains why the United States and other nations are considering deep geologic disposal as the solution. The overview describes why the United States is considering Yucca Mountain and how a monitored geologic repository would work in the mountain. It presents a repository design, an assessment of its expected performance, and an evaluation of the possible effects on people living near Yucca Mountain. Also presented is the work remaining to be completed prior to a license application, along with the estimated cost of building and operating a geologic repository at Yucca Mountain. Finally, based on the information in the viability assessment, the overview concludes with DOE's assessment of whether work at Yucca Mountain should proceed.

Results in brief

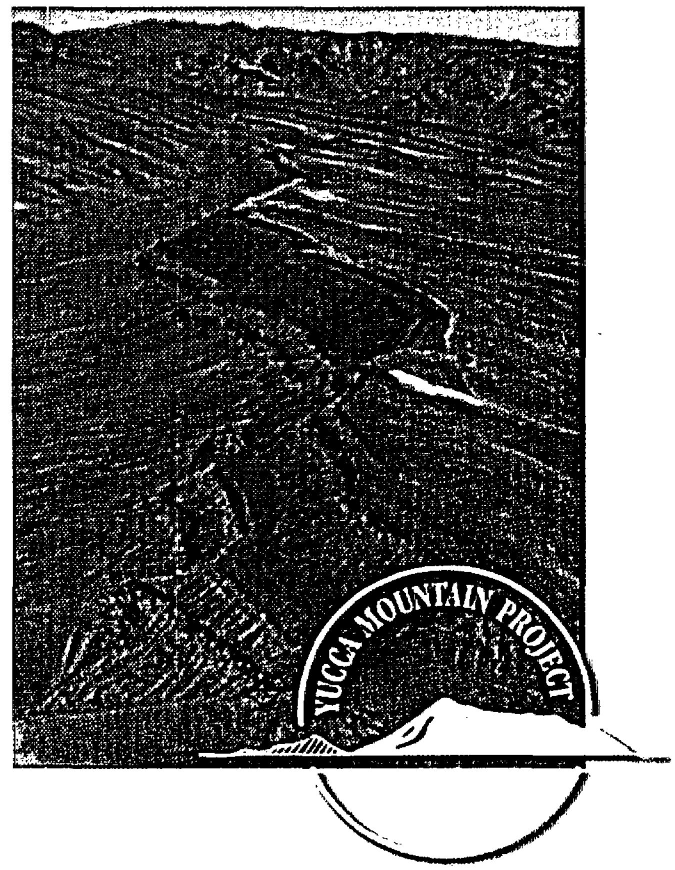
Based on the viability assessment, DOE believes that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository. For the site to be recommended, DOE needs to demonstrate that a repository can be designed and built at Yucca Mountain that would protect public health and safety and the environment for thousands of years. Uncertainties remain about key natural processes, the preliminary design, and how the site and design would interact. To address these uncertainties, DOE plans to advance the design, complete critical tests and analyses, and prepare draft and final environmental impact statements. When this work is completed in 2001, a decision will be made by the Secretary of Energy on whether to recommend the site to the President.

The advantages of Yucca Mountain as a potential repository site include its location, semiarid climate, and deep groundwater table.

- Yucca Mountain is about 100 miles northwest of Las Vegas, Nevada, on unpopulated land owned by the Federal Government and adjacent to the Nevada Test Site. More than 900 nuclear weapons tests have been conducted at the Nevada Test Site.

- Water is the primary means by which radioactive elements (radionuclides) could be transported from a repository. Yucca Mountain is located in a desert environment, with an average rainfall of about 7 inches per year.

- The nearest groundwater, which is about 1,000 feet below the planned location of the repository, is isolated in a closed regional basin and does not flow into any rivers that reach the ocean. This closed basin feature is unique to the western region of the country.



The preliminary repository design includes a long-lived waste package and takes advantage of the desert environment and geologic features of Yucca Mountain. Together, the natural and engineered barriers can keep water away from the waste for thousands of years. Analyses of the preliminary design using mathematical models, though subject to uncertainties, indicate that public health and the environment can be protected.

- For 10,000 years after the repository is closed, people living near Yucca Mountain are expected to receive little or no increase in radiation exposure.

- The maximum radiation exposure from the repository is expected to occur after about 300,000 years. People living approximately 20 kilometers (12 miles) from Yucca Mountain at that time might receive additional radiation exposures equivalent to present-day background radiation.

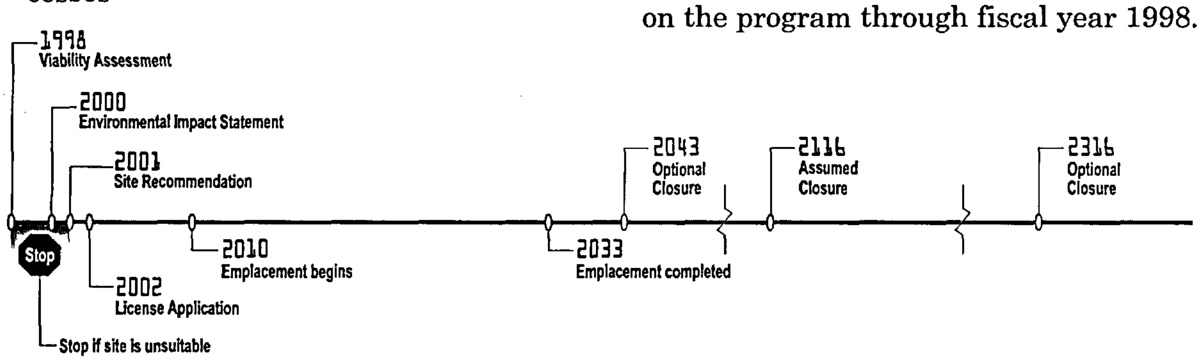
Although current assessments of repository performance are encouraging, more work is needed before the site can be recommended and a license application for construction of a repository can be submitted to the Nuclear Regulatory Commission (NRC).

Current schedules anticipate that the Secretary of Energy will decide whether to recommend the site to the President in 2001, after considering the views of States, affected Indian tribes, and NRC, as required by the Nuclear Waste Policy Act. In turn, the President will decide whether to recommend the site to Congress. If Congress agrees with the President's recommendation and the site is designated, DOE would submit to NRC in 2002 a license application for construction authorization. To support these plans, DOE will:

- Obtain more information on key natural processes, including how radionuclides could be transported by groundwater beneath the repository
- Test the performance of candidate waste package materials and evaluate alternative repository designs
- Continue analyzing the interaction between the repository and the natural processes
- Prepare an environmental impact statement, publish it for public comment in 1999, and finalize it in 2000

These tasks will cost approximately $1.1 billion to complete. If the site is suitable and DOE submits a license application in 2002, the estimated cost to successfully complete the licensing process, build a licensed repository, emplace the waste, and monitor and close the repository is approximately $18.7 billion, in constant 1998 dollars. Given adequate funding and successful completion of the licensing process, the first waste could be emplaced in a repository in 2010, and the last waste, in 2033. With NRC approval, a repository could be closed and sealed as early as 10 years after the last waste is emplaced; or it could be kept open and actively monitored for hundreds of years, if it appears desirable to do so. The $18.7 billion cost estimate assumes a monitoring period of 100 years, beginning with initial waste emplacement. The repository is being designed to allow future generations to decide how long the repository should be monitored, and whether and when to close and seal it.

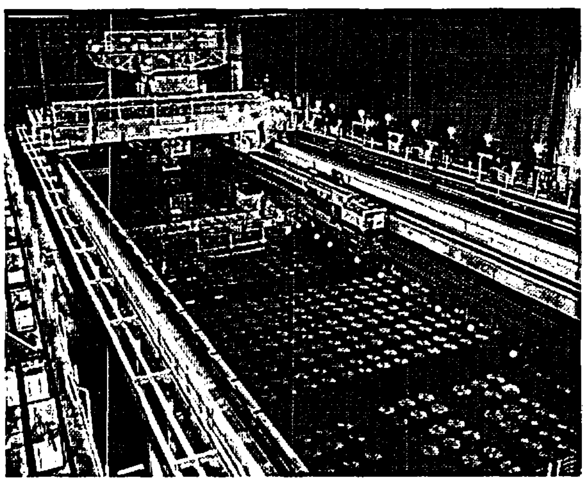
A monitored geologic repository is one component of a total waste management system. The total estimated future cost to complete the program, including transportation of waste and storage at the repository, is $36.6 billion, in constant 1998 dollars. This includes costs from 1999 through closure and decommissioning, assumed to begin in 2110 and to be completed in 2116. It does not include $5.9 billion that has been spent on the program through fiscal year 1998.



Schedule for major repository milestones

The nuclear waste problem

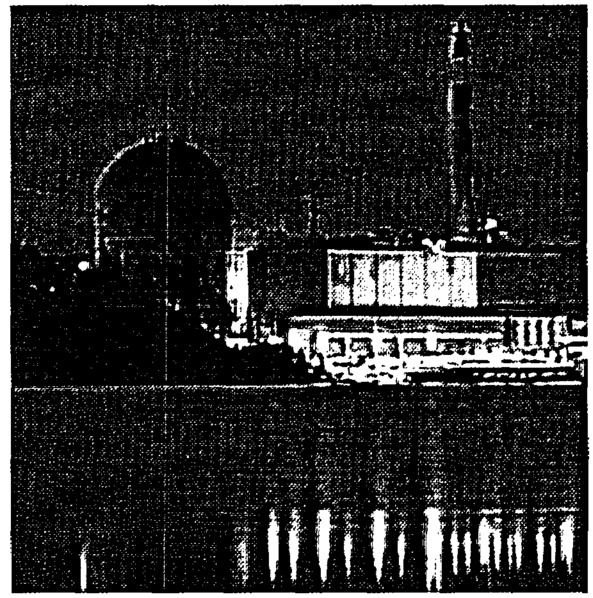
Countries worldwide have accumulated high-level radioactive waste by using nuclear materials to produce electricity, to power naval vessels, and to make nuclear weapons. Some elements of this waste are hazardous for a few years to several hundred years; some elements are hazardous for many thousands of years. This waste must be safely contained until it no longer poses a significant risk to human health and the environment.[2]



Storage pool for commercial spent nuclear fuel

Commercial spent nuclear fuel

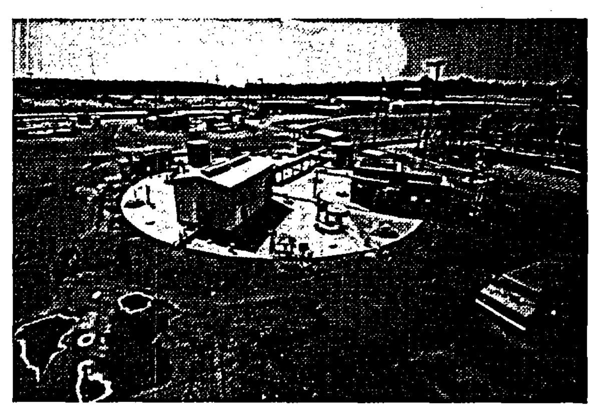
As of December 1998, the United States had accumulated 38,500 metric tons of used or "spent" nuclear fuel from commercial nuclear power plants; this amount could more than double by the year 2035 if all currently operating plants complete their initial 40-year license period. The spent fuel is now stored in 33 states at 72 power plant sites and one commercial storage site and is likely to remain where it is until a disposal or central storage facility is constructed. When a power plant ceases operations, the spent nuclear fuel and other radioactive materials must be removed before the plant can be fully decommissioned and the site used for other purposes.



Indian Point Nuclear Power Plant, Buchanan, NY

DOE spent nuclear fuel

By 2035, the United States will have accumulated approximately 2,500 metric tons of spent nuclear fuel from reactors that produce materials for nuclear weapons, from research reactors, and from reactors on the Navy's nuclear-powered ships and submarines. The majority of DOE spent nuclear fuel is currently stored at three major sites in Idaho, South Carolina, and Washington. Under a negotiated settlement agreement between the State of Idaho, the Navy, and DOE, all spent fuel must be removed from Idaho by the year 2035.[3]



F Area Tank Farm at Savannah River Site, near Aiken, SC

High-level radioactive waste

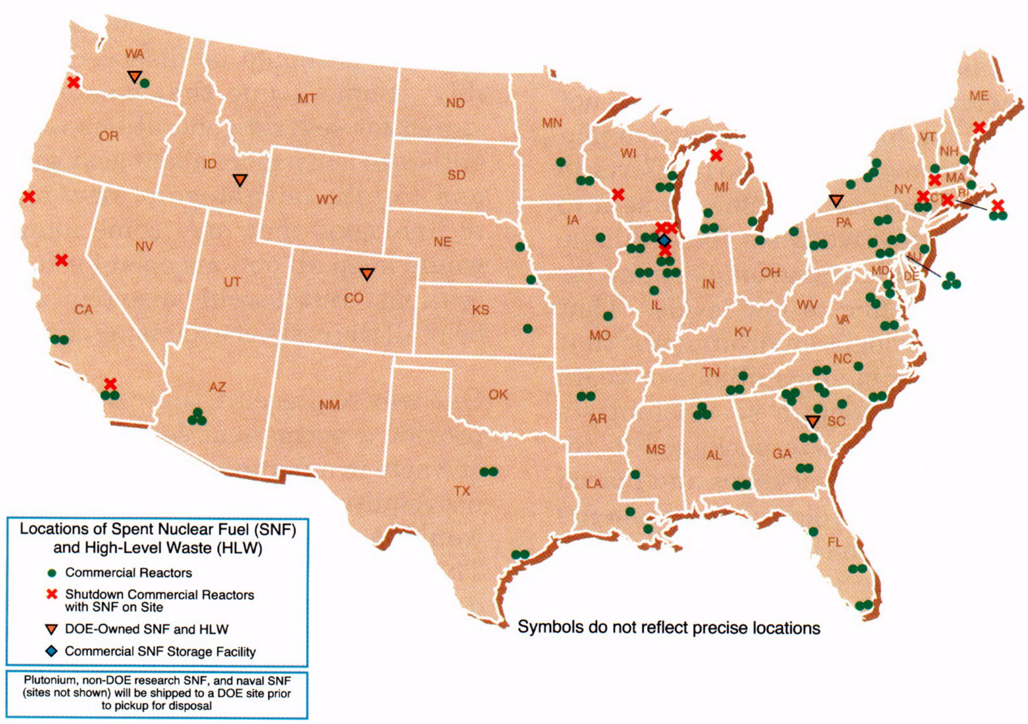
The production of nuclear weapons has left a legacy of high-level radioactive waste that was created when spent nuclear fuel was treated chemically to separate uranium and plutonium. The remaining high-level waste is in liquid and solid forms; 100 million gallons are stored in underground tanks in Washington, South Carolina, Idaho, and New York.[4] Under agreements between DOE and the states where the waste is stored, this high-level waste will continue to be solidified and placed in about 20,000 canisters for future disposal in a permanent geologic repository.

Surplus plutonium and other nuclear weapons materials

The end of the Cold War has brought the problem of cleaning up and closing weapons plants that are no longer needed and disposing of surplus plutonium and other nuclear materials associated with weapons production. These radioactive materials must be disposed of in a secure facility that will not only keep the waste away from people but will also keep people away from the weapons-usable material for thousands of years. Ensuring national security and preventing the proliferation of nuclear weapons depends on developing a permanent, safe, and secure disposal facility for surplus plutonium and other weapons materials.

Total inventory

At present, spent nuclear fuel and high-level radioactive waste are temporarily stored at 78 locations in 35 states, as shown below. Some of these storage sites are close to population centers and are located near rivers, lakes, and seacoasts. The stored materials, if left where they are indefinitely, could become a hazard to nearby populations and the environment. These nuclear materials require safe and permanent disposal.



Locations of spent nuclear fuel and high-level radioactive waste destined for geologic disposal

As of October 30, 1998

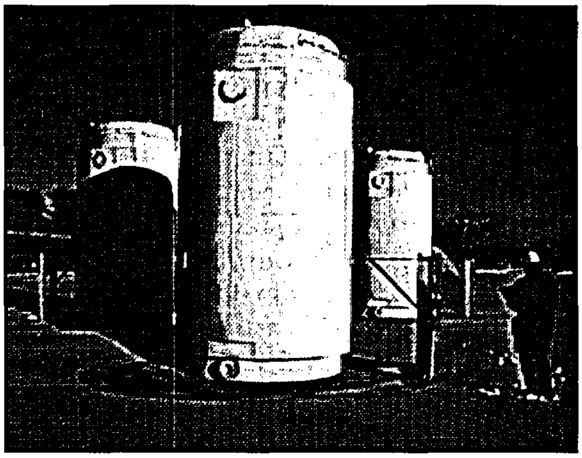
C-01

Geologic disposal

Geologic disposal of radioactive waste has been the focus of scientific research for more than 40 years. As early as 1957, a National Academy of Sciences' report to the Atomic Energy Commission recommended burying radioactive waste in geologic formations.[5] In 1962, the Atomic Energy Commission began investigating salt formations, including bedded salt and salt domes, as potential host rock for repositories. In 1975, the Energy Research and Development Administration, predecessor to DOE, selected a site near Carlsbad, New Mexico, for the Waste Isolation Pilot Project, which is to dispose of transuranic waste. In 1976, the Energy Research and Development Administration also began to investigate other geologic formations and to consider different disposal concepts, including deep-seabed disposal, disposal in the polar ice sheets, and rocketing waste into the sun. After extensive evaluation of the options, DOE concluded in 1981 that disposal in an underground mined geologic repository remained the preferred option.[6]

Unlike the hazards of toxic materials such as lead, mercury, and arsenic, which do not break down, the hazard of radioactive materials declines over time. Early efforts to study disposal options, therefore, sought to find the most effective ways for available technology to isolate waste long enough for the hazard to decline to low levels. That search led to geologic environments that have remained stable for millions of years and are likely to remain so. Scientists widely agreed that waste packaged in robust, long-lived waste packages and placed deep in such stable geologic environments could be isolated from the biosphere for the long time periods necessary.

Since the first scientific study in 1957, virtually every expert group that has looked at the nuclear waste problem has agreed that a geologic repository is the best approach for nuclear waste disposal. A panel of the National Academy of Sciences noted in 1990 that there is "a worldwide scientific consensus that deep geological disposal, the approach being followed by the United States, is the best option for disposing of high-level radioactive waste."[7]



Dry cask storage of commercial spent nuclear fuel

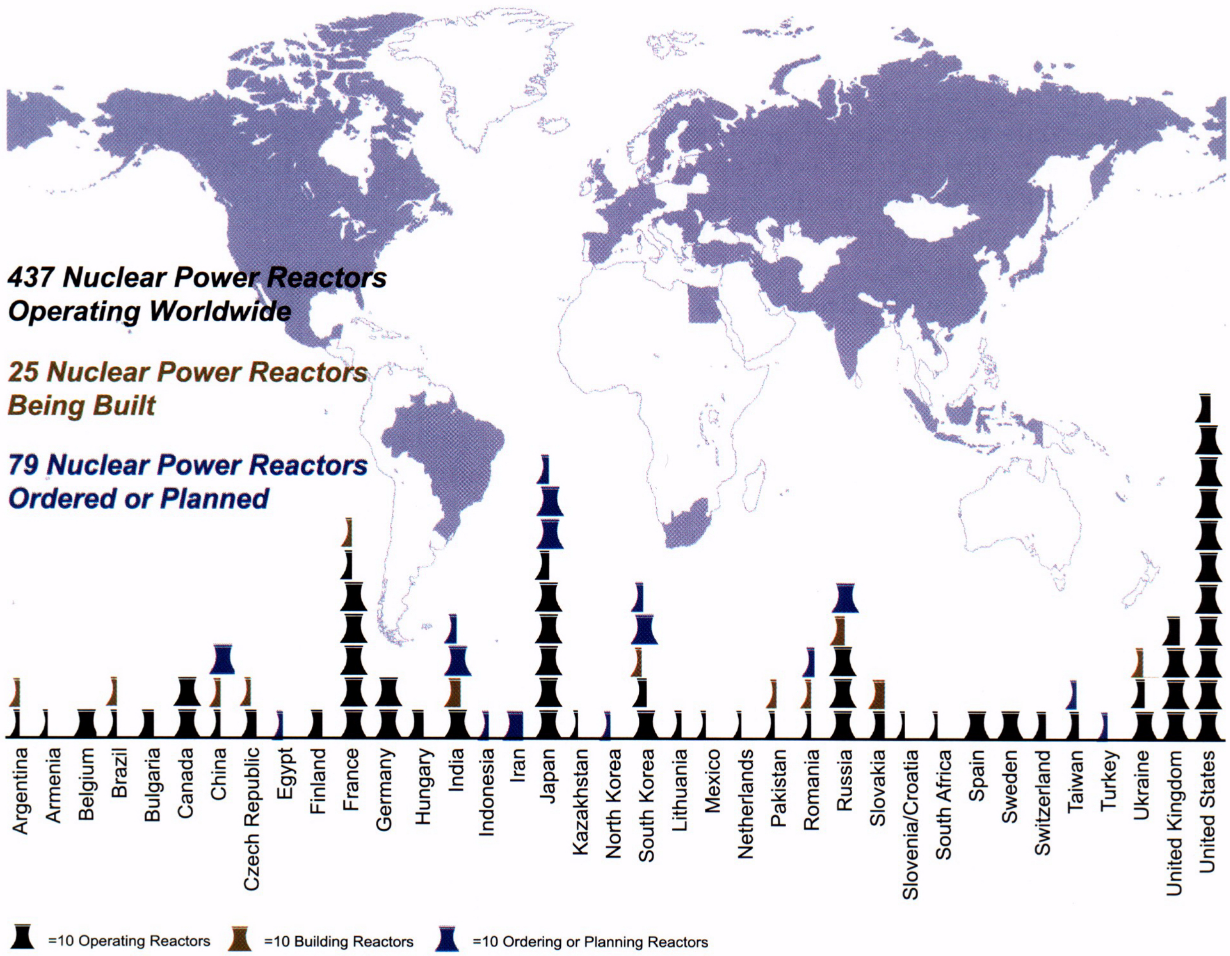
However, there are differing views on how rapidly waste should be disposed of and whether it should be disposed of irreversibly. Some argue that waste should be stored for several generations to allow scientists to learn more about geologic disposal and to take advantage of new and better technologies that may come along. That would keep all options open for future generations. But it would also require them to bear all the costs of exercising those options.

One way to preserve these options and still provide a permanent solution is to dispose of waste in a manner that permits, but does not require, the retrieval of waste; the waste would be disposed of, but not irreversibly. The Nuclear Waste Policy Act of 1982 [8] requires that spent nuclear fuel emplaced in a repository be retrievable for any reason pertaining to public health and the environment, or to permit recovery of the potentially valuable contents of the spent fuel prior to permanent closure of a repository.

Nuclear Regulatory Commission (NRC) regulations require that a geologic repository be designed for waste retrieval at any time up to 50 years after waste emplacement begins.[9]

The DOE is designing a monitored geologic repository at Yucca Mountain that could give future generations the choice of closing and sealing the repository as early as allowable under NRC regulations, or of keeping it open and monitoring it for hundreds of years.

A geologic repository will not require perpetual human care and will not rely on the stability of society for thousands of years into the future. It will rely instead on geologic formations that have remained relatively stable for millions of years and on long-lived engineered barriers.



Worldwide status of nuclear power reactors. In the United States, 104 operating reactors produce 20 percent of the nation's electricity. Worldwide data is from the files of the Australian Nuclear Science and Technology Organisation, based on information as of June 5, 1998.

C-02

The law and the regulations

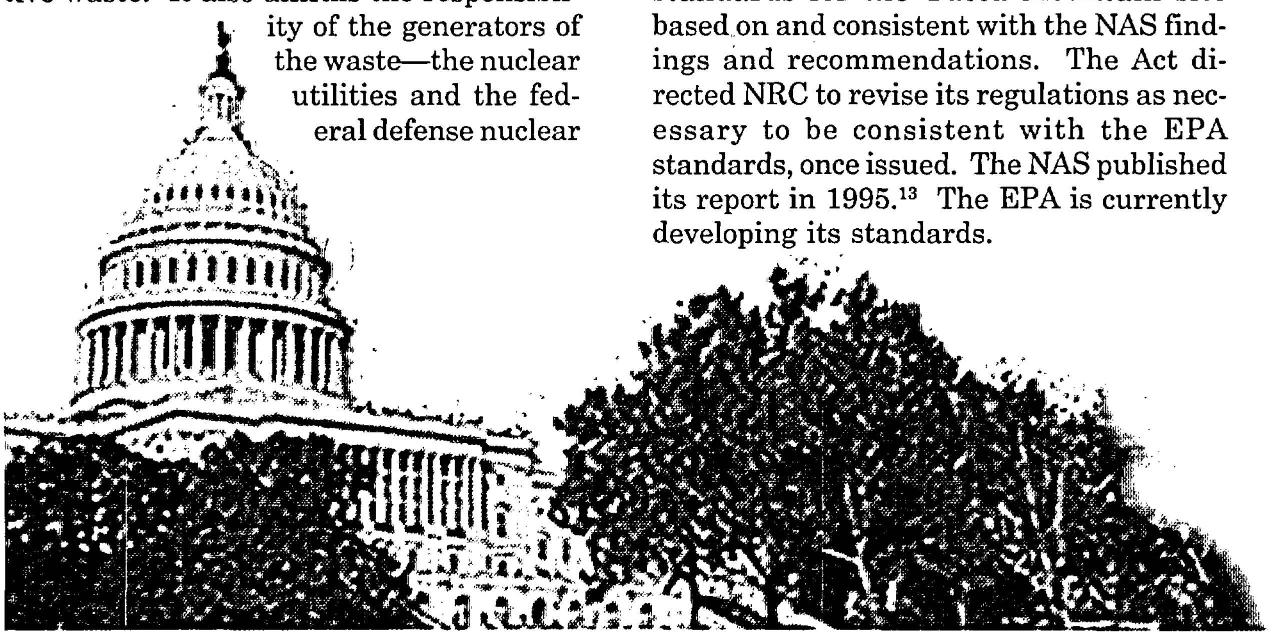
The Nuclear Waste Policy Act of 1982 (NWPA) directed DOE to develop a system for the safe and final disposal of spent nuclear fuel and high-level radioactive waste.

The NWPA set an ambitious schedule for DOE to site two geologic repositories and required DOE to contract with utilities to begin disposal in the first one by January 31, 1998. The DOE formally identified nine potentially acceptable sites across the nation and later narrowed the list to three sites: Deaf Smith County, Texas; Hanford, Washington; and Yucca Mountain, Nevada. In 1987, Congress directed DOE to study only one of the sites—the one at Yucca Mountain—to decide whether it is suitable for a repository. This legislation, known as the Nuclear Waste Policy Amendments Act of 1987,[10] also established the Nuclear Waste Technical Review Board, composed of experts appointed by the President to review the DOE program.

The NWPA reaffirms the Federal Government's responsibility for developing repositories for the permanent disposal of spent nuclear fuel and high-level radioactive waste. It also affirms the responsibility of the generators of the waste—the nuclear utilities and the federal defense nuclear program—to pay for that effort. The NWPA requires utilities with nuclear power plants to pay a fee to fund the disposal program. The Federal Government bears the costs of disposing of defense waste.

The NWPA also assigns distinct roles to the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC). The EPA is required to establish standards for protection of the general environment from releases of radioactive material from a repository. The NRC is responsible for establishing technical requirements and criteria, consistent with EPA standards, for approving or disapproving applications to construct, operate, and eventually close a repository. In 1981 and 1983, NRC issued regulations for a geologic repository in anticipation of EPA standards.[11]

Subsequently, the Energy Policy Act of 1992[12] modified the process for setting environmental standards for a repository at Yucca Mountain. The Act directed the National Academy of Sciences (NAS) to provide findings and recommendations on these standards and directed EPA to issue standards for the Yucca Mountain site based on and consistent with the NAS findings and recommendations. The Act directed NRC to revise its regulations as necessary to be consistent with the EPA standards, once issued. The NAS published its report in 1995.[13] The EPA is currently developing its standards.



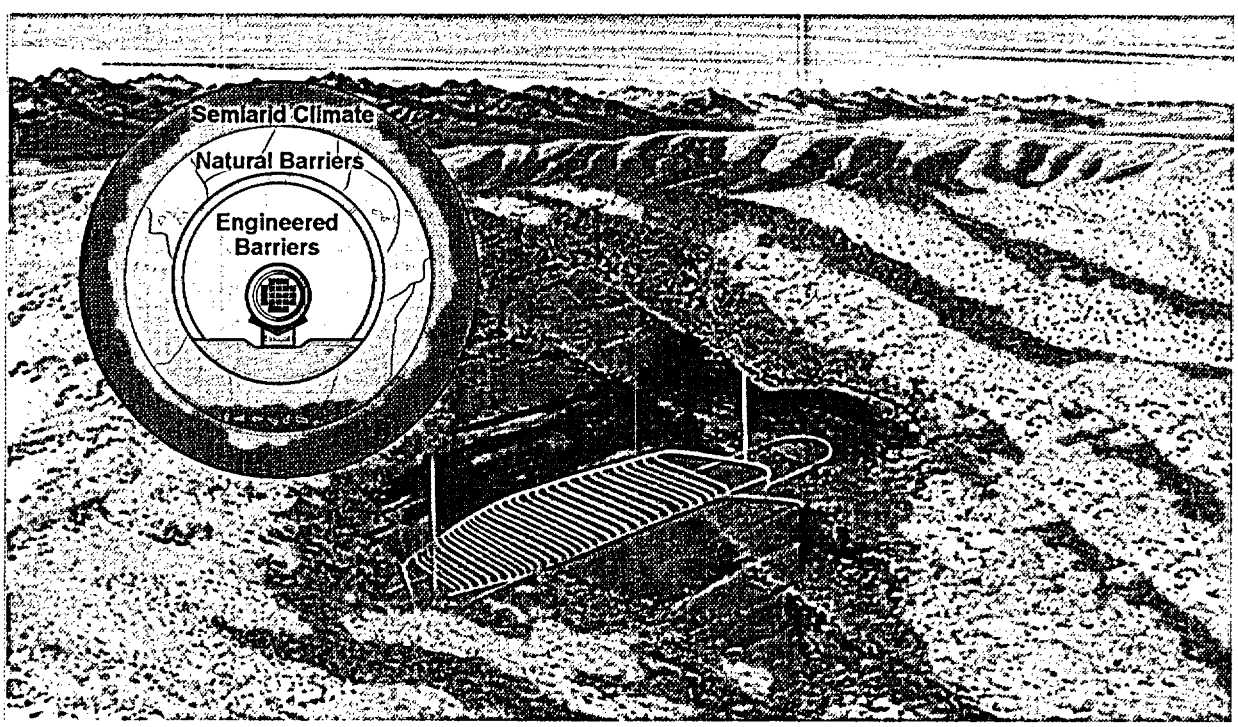
How geologic disposal would work

The basic concept of geologic disposal is to place carefully prepared and packaged waste in excavated tunnels in geologic formations such as salt, hard rock, or clay. The concept relies on a series of barriers, natural and engineered, to contain the waste for thousands of years and to minimize the amount of radioactive material that may eventually be transported from a repository and reach the human environment.

Water is the primary means by which radionuclides could reach the human environment. Therefore, the primary functions of the barriers are to keep water away from the waste as long as possible, to limit the amount of water that finally does contact the waste, to slow the release of radionuclides from the waste, and to reduce the concentrations of radionuclides in groundwater.

All countries pursuing geologic disposal are taking the multibarrier approach, though they differ in the barriers they emphasize. The German disposal concept, for example, relies heavily on the geologic barrier, the rock salt formation at the prospective disposal site. The Swedish method, on the other hand, relies heavily on thick copper waste packages to contain waste.

The U.S. approach, as recommended in the 1979 Report to the President by the Interagency Review Group on Nuclear Waste Management,[14] is to design a repository in which the natural and engineered barriers work as a system, so that some barriers will continue to work even if others fail, and so that none of the barriers is likely to fail for the same reason or at the same time. This design strategy is called defense in depth. The barriers include the chemical and physical forms of the waste, the waste packages and other engineered barriers, and the natural characteristics of Yucca Mountain.



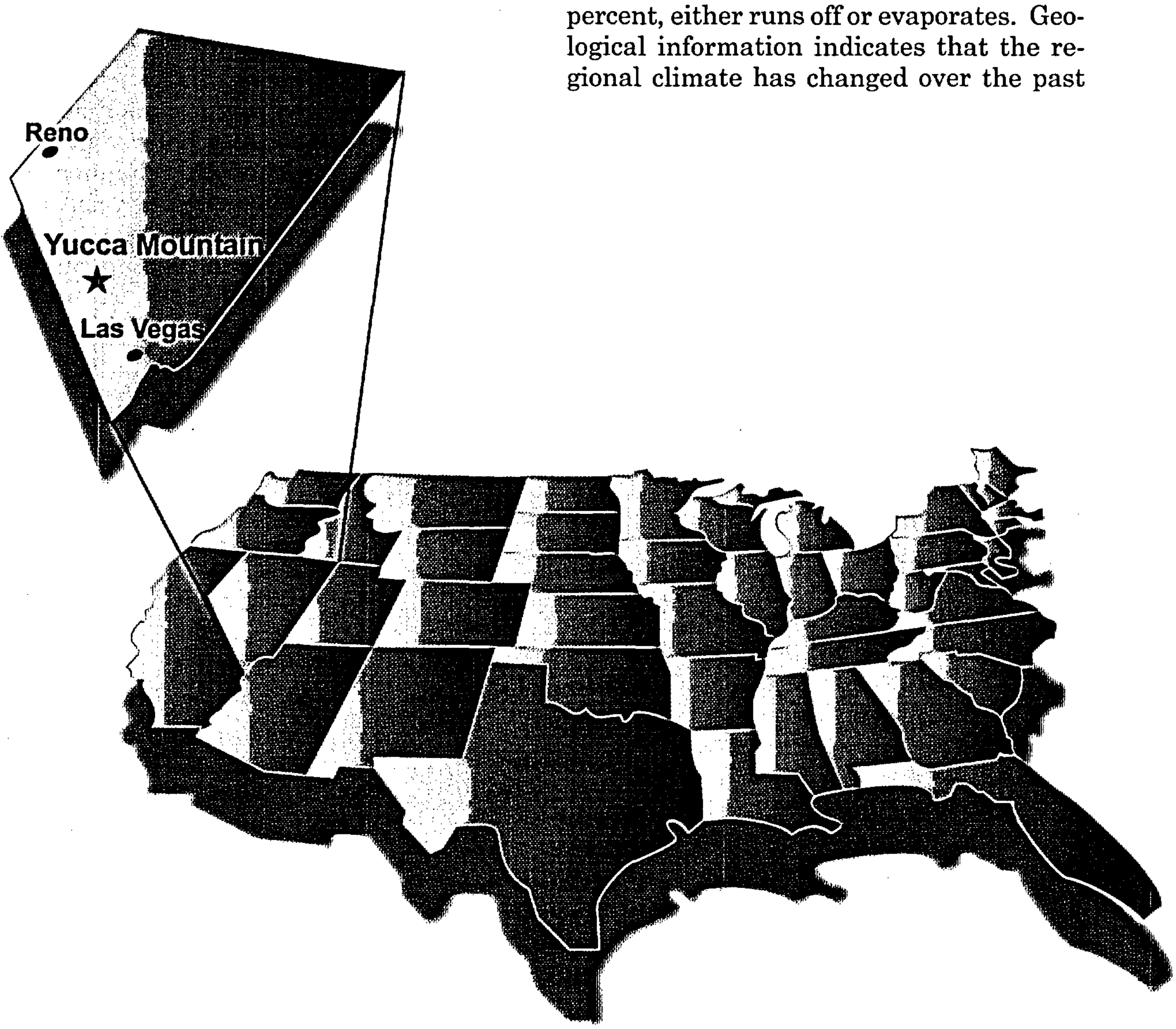
Cutaway showing artist's concept of the complex of underground tunnels into which waste would be emplaced. A repository at Yucca Mountain would rely on the semiarid climate, natural barriers, and engineered barriers to contain and isolate waste for thousands of years.

Why Yucca Mountain?

Yucca Mountain is remote from population centers. Located about 100 miles northwest of Las Vegas, Nevada, Yucca Mountain is on the edge of the nation's nuclear weapons test site, where more than 900 nuclear tests have been conducted. This unpopulated land is owned by the Federal Government.

Yucca Mountain provides a stable geologic environment. A flat-topped ridge running six miles from north to south, Yucca Mountain has changed little over the last million years. Based upon what is known about the site, disruption of a repository at Yucca Mountain by volcanoes, earthquakes, erosion, or other geologic processes and events appears to be highly unlikely.

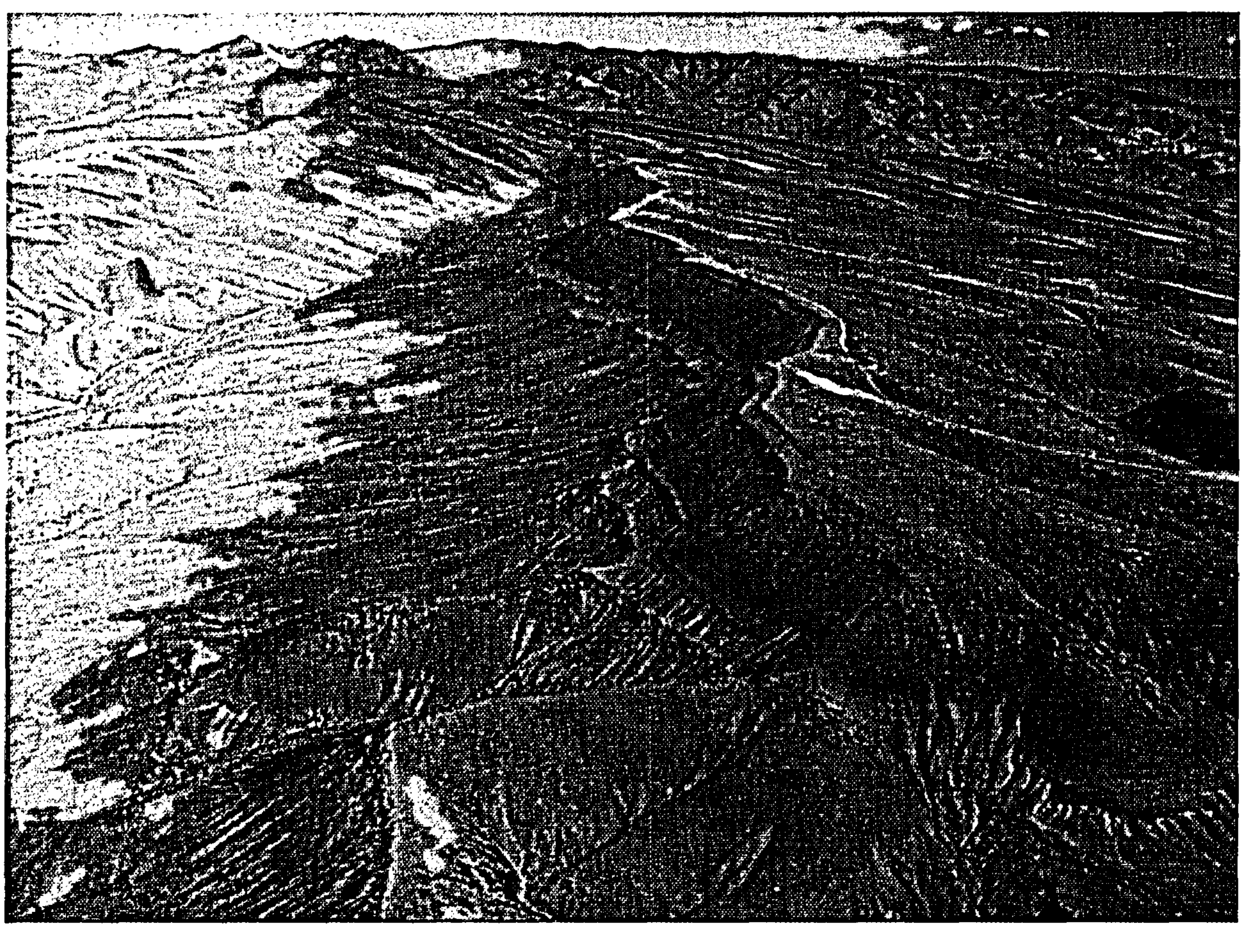
Yucca Mountain has a desert climate. This is important because water movement is the primary means by which radioactive waste could be transported from a repository. On average, Yucca Mountain currently receives about seven inches of rain and snow per year. Nearly all the precipitation, about 95 percent, either runs off or evaporates. Geological information indicates that the regional climate has changed over the past



Location of the proposed monitored geologic repository at Yucca Mountain, Nevada million years and the long-term average precipitation has been about 12 inches per year—comparable to that of present-day Santa Fe, New Mexico. Even if this were to be the case in the future, most of the water would run off or evaporate rather than soak into the ground and possibly reach the repository.

A repository would be built about 1,000 feet below the surface and 1,000 feet above the water table in what is called the unsaturated zone. The water table is about 2,000 feet beneath the crest of Yucca Mountain. Any precipitation that does not run off or evaporate at the surface would have to seep down nearly 1,000 feet before reaching the repository. Between the repository and the water table, it would have to move through another 1,000 feet of the unsaturated zone before reaching the water table. The groundwater in the region is trapped within a closed desert basin and does not flow into any rivers that reach the ocean.

The concept of disposing of waste in the unsaturated zone in the desert regions of the Southwest was first advanced by the U.S. Geological Survey in the 1970s. In 1976, the director of the Geological Survey suggested that the region in and around the Nevada nuclear weapons test site offered a variety of geologic formations and other attractive features, including remoteness and an arid climate.[15] In 1981, a Geological Survey scientist noted that the desert Southwest has water tables that are among the deepest in the world and that the region contains multiple natural barriers that could isolate wastes for "tens of thousands to perhaps hundreds of thousands of years."[16]



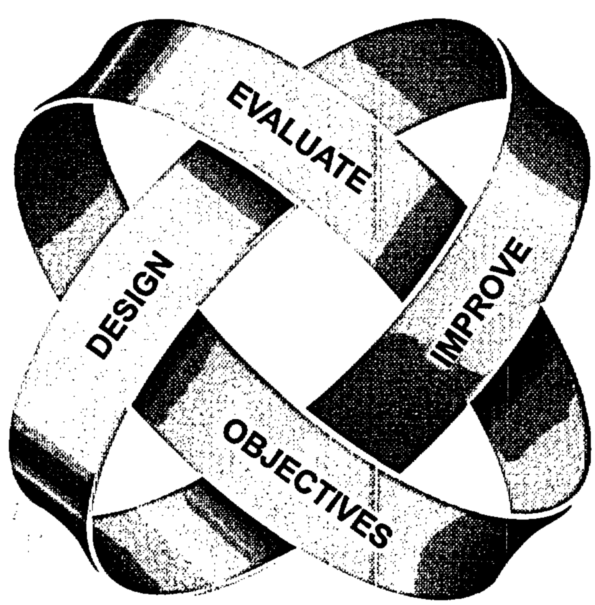
View of Yucca Mountain from the south

The design process

Designing a repository is an iterative process. The process begins with defining the primary design objectives: protecting the health and safety of both the workers and the public during the period of repository operations; minimizing the amount of radioactive material that may eventually reach the accessible environment; and keeping costs down to an acceptable level.

To achieve the design objectives, engineers work with scientists to design the man-made components of a repository to work effectively with the natural system. The engineered barriers are intended to work with the natural barriers—the geology and climate of Yucca Mountain—to contain and isolate waste for thousands of years. The waste package design, for example, includes materials that are chosen to be compatible with the underground thermal and geochemical environment, and the layout of tunnels takes into consideration the geology of the mountain.

Through successive evaluations and improvements, the repository design has evolved to the current reference design. The reference design represents a snapshot of the ongoing design process, thus providing a frame of reference to describe how a repository at Yucca Mountain could work. The repository design also offers insights about how to reduce uncertainty and modify the design to improve its performance. Improvements are expected to continue as more work is completed and more information about the site is obtained.



A conceptual model of the design process. Design objectives for repository components are identified, and then the designs are developed, evaluated, and improved.

The reference design

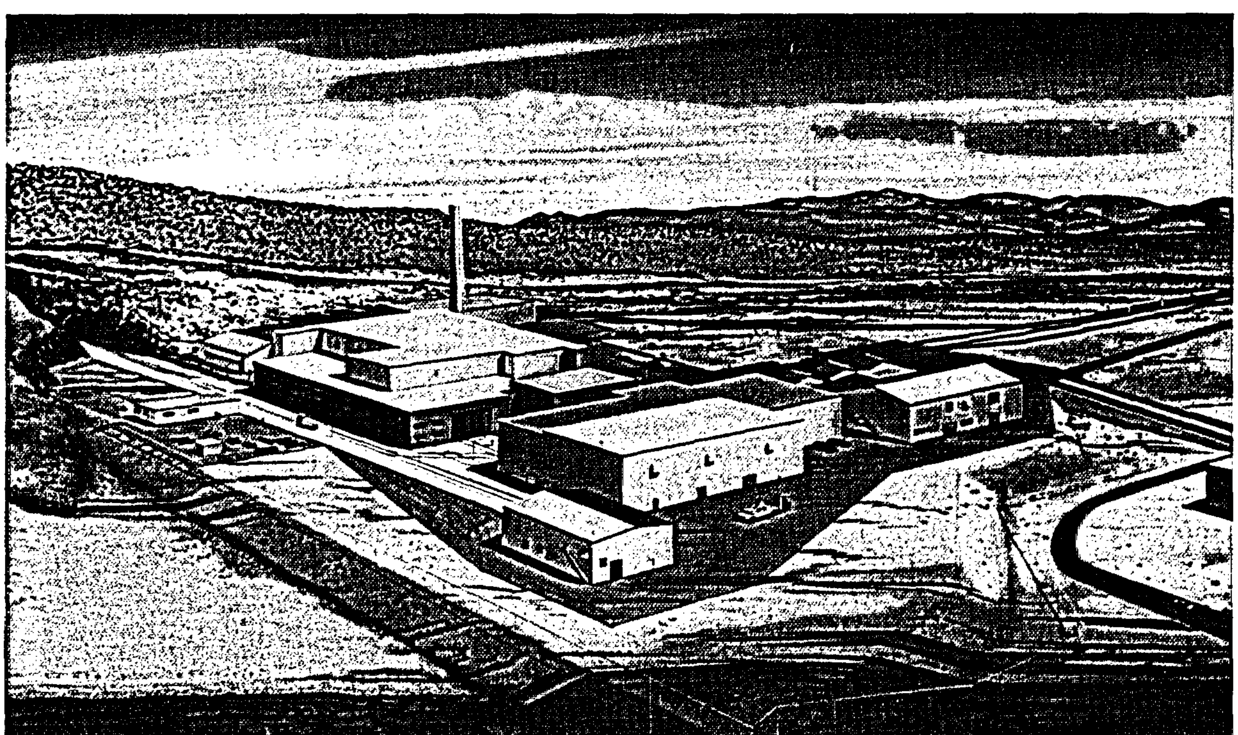
In the current reference design, spent nuclear fuel and high-level radioactive waste would be transported to Yucca Mountain by truck or rail in specially designed, shielded shipping containers licensed by the Nuclear Regulatory Commission; removed from the shipping containers and placed in long-lived waste packages for disposal; carried into the underground repository by rail cars; placed on supports in the tunnels; and monitored until the repository is finally closed and sealed.

Surface facilities and operations

Surface facilities would be designed to receive the waste and prepare it for final disposal, and to support the excavation, construction, loading, and ventilation of the repository tunnels. The entire surface layout would cover about 100 acres and have three main areas:

- At the north entrance to the underground repository would be the facilities and equipment to transfer waste from shipping containers to waste packages. Each waste package would be welded closed and thoroughly checked before being loaded onto a shielded transporter to be taken underground.
- At the south entrance would be the facilities to support the excavation and construction of the tunnels.
- Near the top of the mountain would be the facilities that house the air intake and exhaust fans for ventilating the repository.

Workers would be shielded from direct exposure to radiation and contamination because waste would be handled remotely.



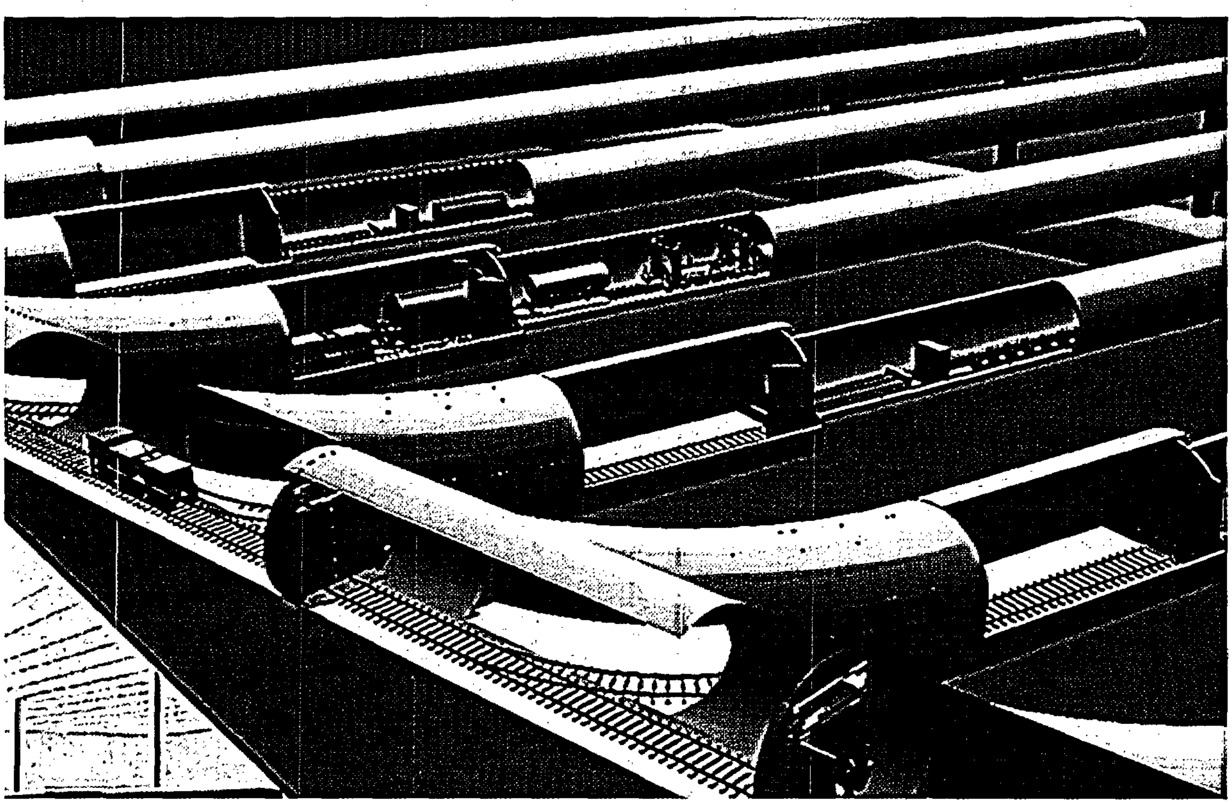
Artist's concept of repository surface facilities

Underground facilities and operations

The underground repository would consist of about 100 miles of tunnels. The main tunnels would be designed for moving workers, equipment, and waste packages. Ventilation tunnels would provide air for workers. The emplacement tunnels (or drifts) would accommodate the waste packages. Two gently sloping access ramps and two vertical ventilation shafts would connect the underground and surface areas.

Transportation underground would be by rail. A locomotive would haul the shielded transporter with its waste package underground from the waste-handling building to the entrance of an emplacement drift. Then a remotely operated crane (or gantry) would lift the waste package, carry it along the drift, and lower it onto its supports.

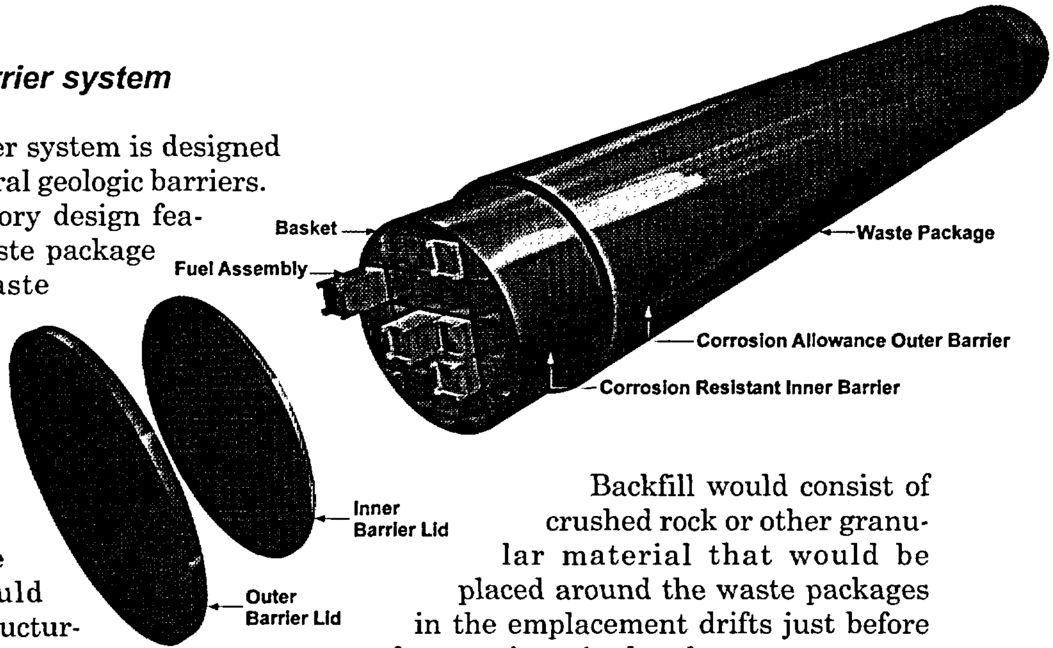
Current schedules anticipate that waste emplacement would begin in 2010 if a license is received from the Nuclear Regulatory Commission, after construction of surface facilities, the main tunnels, ventilation system, and initial emplacement drifts. Additional drifts would be constructed over a period of about 20 years while waste is being emplaced. The current design would accommodate 70,000 metric tons of waste, a limit imposed by the Nuclear Waste Policy Act of 1982. However, the site is large enough to accommodate additional waste, if that were authorized.



Artist's concept of repository underground facilities and operations

The engineered barrier system

The engineered barrier system is designed to work with the natural geologic barriers. The reference repository design features a long-lived waste package and includes the waste form, the concrete tunnel floor (or invert), and the steel and concrete support for the waste package.



The current waste package design would have two layers: a structurally strong outer layer of carbon steel nearly four inches thick, and a corrosion-resistant inner layer of a high-nickel alloy about three-fourths of an inch thick. These two layers would work together to preserve the integrity of the waste package.

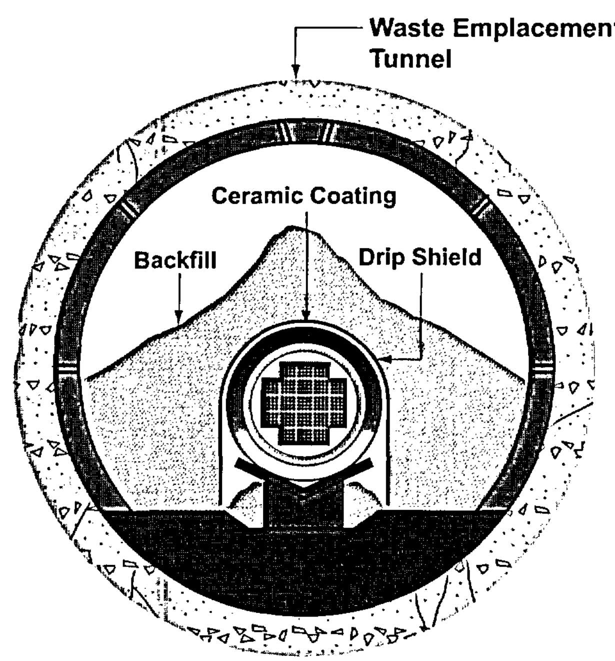
The waste forms inside the waste package would provide additional barriers against transport of radionuclides away from the repository. Most spent nuclear fuel is encased in Zircaloy, a metal cladding that is highly resistant to corrosion. Defense high-level radioactive waste would be solidified as glass inside stainless steel canisters.

As the design process continues, DOE is evaluating several design options that might increase the ability of the engineered barrier system to contain waste. These include the following:

- Drip shields that could keep water from dripping on the waste packages
- Ceramic coating on the waste packages that could further prevent corrosion
- Backfill that could protect the waste packages from falling rock or tunnel collapse, raise the waste packages' temperature and lower the relative humidity

Backfill would consist of crushed rock or other granular material that would be placed around the waste packages in the emplacement drifts just before the repository is closed.

The DOE also is evaluating alternative designs, some of which might reduce uncertainties regarding repository performance. (Design alternatives are discussed further under Long-Term Safety, page 30.)

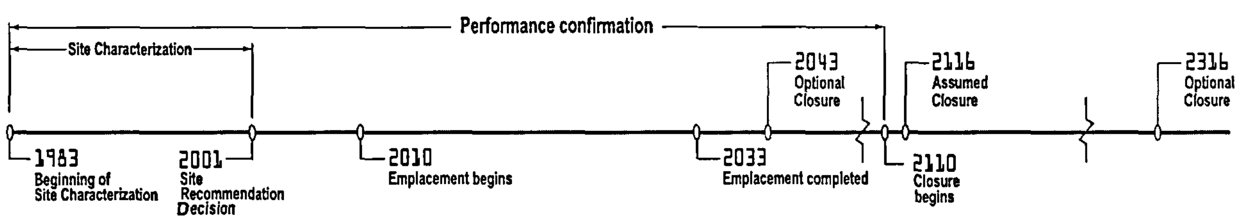


Confirmation and retrieval

Activities to confirm that a repository would work as expected begin long before the first waste is emplaced. In the current site characterization phase, information about Yucca Mountain and the surrounding environment is being collected and compiled to provide a baseline against which to compare what would happen if a repository were built and waste were emplaced.

Using mathematical models based on the collected data and analyses of the engineered components, scientists forecast the probable behavior of the engineered system and the effects of a repository on the Yucca Mountain environment. If repository operations begin, remote sensors would monitor the waste packages, tunnels, and surrounding rock. The effects of a repository would be monitored, and the observed effects would be compared to the model predictions. These confirmation activities would help determine whether a repository is operating as expected.

If a problem is detected prior to closing the repository, remedial action or retrieval of the waste would be possible using remotely operated equipment. The Nuclear Regulatory Commission currently requires that a repository be designed to allow the retrieval of waste at any time up to 50 years after waste operations begin. Retrieval of waste, if needed, would follow, in reverse order, the same steps taken in emplacing the waste.



The performance confirmation program begins with site characterization to establish a baseline and continues until repository closure begins.

Repository closing

Even under the most ambitious schedules for disposal, future generations would make the final decision to close a repository. To give future generations the option of closing the repository or monitoring it for long periods of time, DOE is designing the repository so that it could (with Nuclear Regulatory Commission approval) be either closed as early as 10 years after emplacement of the last waste package, or kept open for hundreds of years from the start of waste emplacement.

Permanently closing the repository would require the sealing of all shafts, ramps, exploratory boreholes, and other underground openings. These actions would discourage any human intrusion into the repository and prevent water from entering through these openings.

At the surface, all radiological areas would be decontaminated, all structures removed, and all wastes and debris disposed of at approved sites. The surface area would be restored as closely as possible to its original condition. Permanent monuments would be erected around the site to warn any future generations of the presence and nature of the buried wastes.

The DOE also would continue to oversee the Yucca Mountain site to prevent any activity that could breach a repository's engineered or geologic barriers, or otherwise increase the exposure of the public to radiation beyond allowable limits.

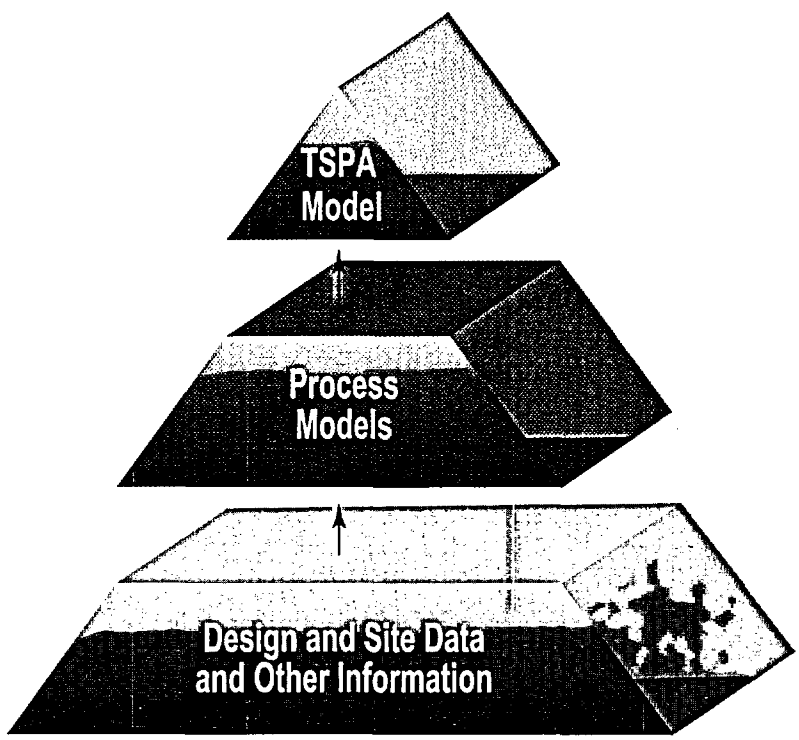
View of Yucca Mountain from the northwest

Performance assessment models

Performance assessment evaluates how a repository system is likely to work over long time periods. From the results of scientific studies, analysts build detailed mathematical models or "representations" of the features, events, and processes that could affect the performance of the design. They then incorporate the results of these detailed process models into an overall model of the repository system, which is called the total system performance assessment model. The models are used to assess how the natural and engineered elements of a waste disposal system are likely to work together over the long period required to isolate wastes.

Performance assessments help identify which uncertainties about the behavior of a disposal system are significant and which are not, which elements of the repository system are most important to how well it is likely to work, and where scientists and engineers might most usefully focus their efforts to improve performance. These assessments are repeated and refined during the course of developing, evaluating, and improving a repository design.

A total system performance assessment represents a reasonable approach to the challenging task of projecting how a repository would work over thousands of years. However, as a National Academy of Sciences panel observed, "Confidence in the disposal techniques must come from a combination of remoteness, engineering design, mathematical modeling, performance assessment, natural analogues and the possibility of remedial action in the event of unforeseen events."[17] The DOE is taking this combined approach.



Approach to constructing a total system performance assessment (TSPA) model. Analysts develop detailed mathematical models of the natural processes that are important to repository performance and then combine these models into a model of the entire repository system.

The attributes of safe disposal

The results of fifteen years of testing and analysis, including four years of underground exploration, have validated many, but not all, of the expectations of scientists who first suggested that remote desert regions are well-suited for a geologic repository. One important and unexpected test result was finding underground, at the level of the proposed repository, traces of a radioactive isotope (chlorine-36) that is associated with above-ground nuclear weapons tests. As atmospheric nuclear testing began in the mid-1940s, this finding suggests that some water travels from the ground surface to the level of the repository in about 50 years or less. Another important finding was evidence that the average amount of water that filters down through the mountain is about a third of an inch per year, which, while only about five percent of the average annual precipitation, is more than DOE initially expected. Taken together, the findings, both expected and unexpected, underscore the importance of building engineered barriers that work with the natural barriers to keep water away from the waste.

The results indicate that a repository at Yucca Mountain would need to exhibit four key attributes to protect public health and the environment for thousands of years. The four key attributes are:

- Limited water contact with waste packages
- Long waste package lifetime
- Low rate of release of radionuclides from breached waste packages
- Reduction in the concentration of radionuclides as they are transported from breached waste packages

Based on performance assessment models, DOE has evaluated the degree to which the reference design exhibits these four key attributes, and has identified additional scientific studies and design improvements that could reduce uncertainties and enhance long-term repository performance.

Limited water contact with waste packages

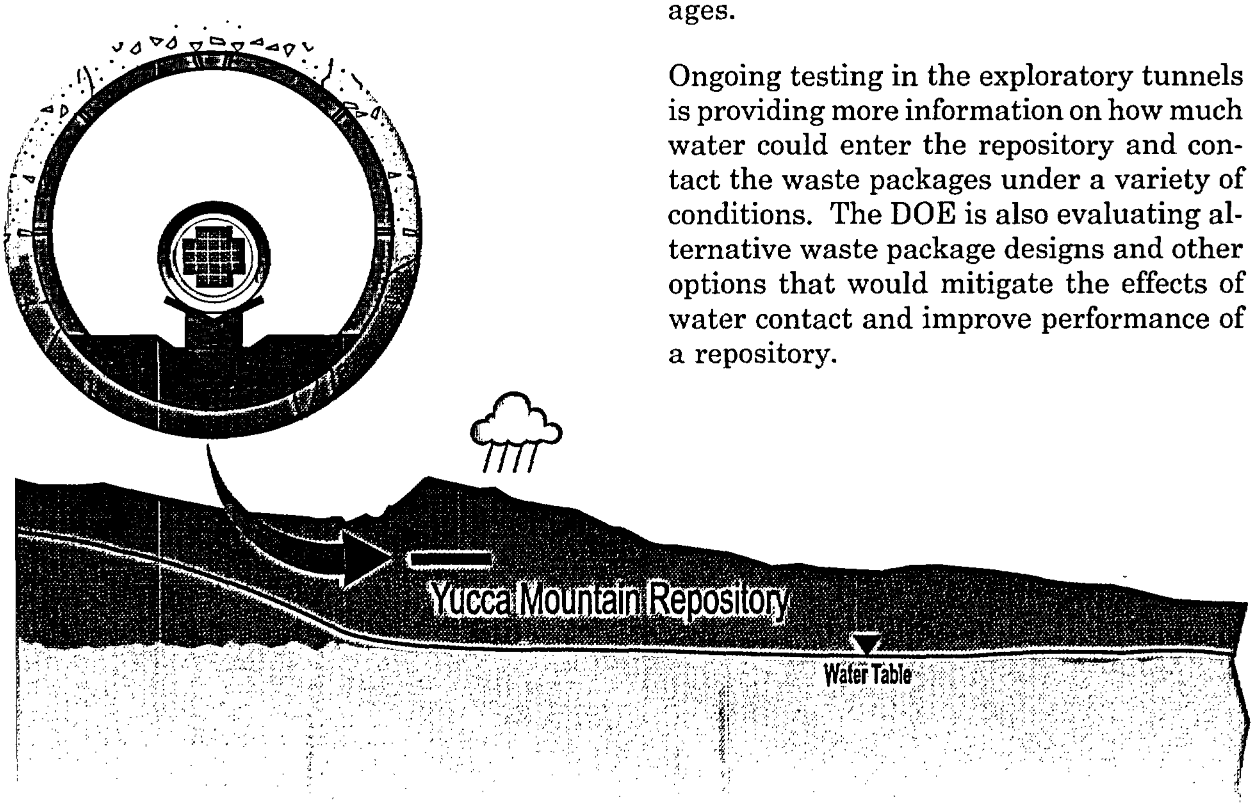
In the reference design, waste packages would be placed about 1,000 feet below the mountain's surface and about 1,000 feet above the water table. Even if future climates are much wetter than today, the mountain is not expected to erode and leave the waste exposed, and the water table is not expected to rise high enough to reach the waste.

In the current semiarid climate, about seven inches of water a year from rain and snow fall on Yucca Mountain. Nearly all of that precipitation, about 95 percent, runs off or evaporates. Only about one-third of an inch of water per year moves down (or percolates) through the nearly 1,000 feet of rock to reach the level of the repository. Studies of past climates indicate that the precipitation may increase to a long-term average of about 12 inches per year. However, most of the water still would run off or evaporate rather than soak into the ground.

Once waste packages have been placed in the repository, the heat generated from radioactive decay would raise the temperature in the tunnels above the boiling point of water. The heat is expected to dry out the surrounding rock and drive any water away for hundreds to thousands of years. However, as the waste decays and the repository cools, enough water to cause drips would begin to seep into the drifts through fractures in the rock.

Using mathematical models, analysts estimate that, after the repository cools enough, about five percent of the packages could experience dripping water, under the current climate. If the climate changes to a wetter long-term average, about 30 percent of the packages could experience dripping water. These estimates are based on a number of assumptions that remain to be validated. Nonetheless, the results suggest that limited water would contact the waste packages.

Ongoing testing in the exploratory tunnels is providing more information on how much water could enter the repository and contact the waste packages under a variety of conditions. The DOE is also evaluating alternative waste package designs and other options that would mitigate the effects of water contact and improve performance of a repository.



Long waste package lifetime

The waste package in the reference design has two layers: a thick outer layer made of carbon steel that provides structural strength and delays any contact of water with the inner layer, and a thinner inner layer of a high-nickel alloy that resists corrosion after the outer layer is penetrated.

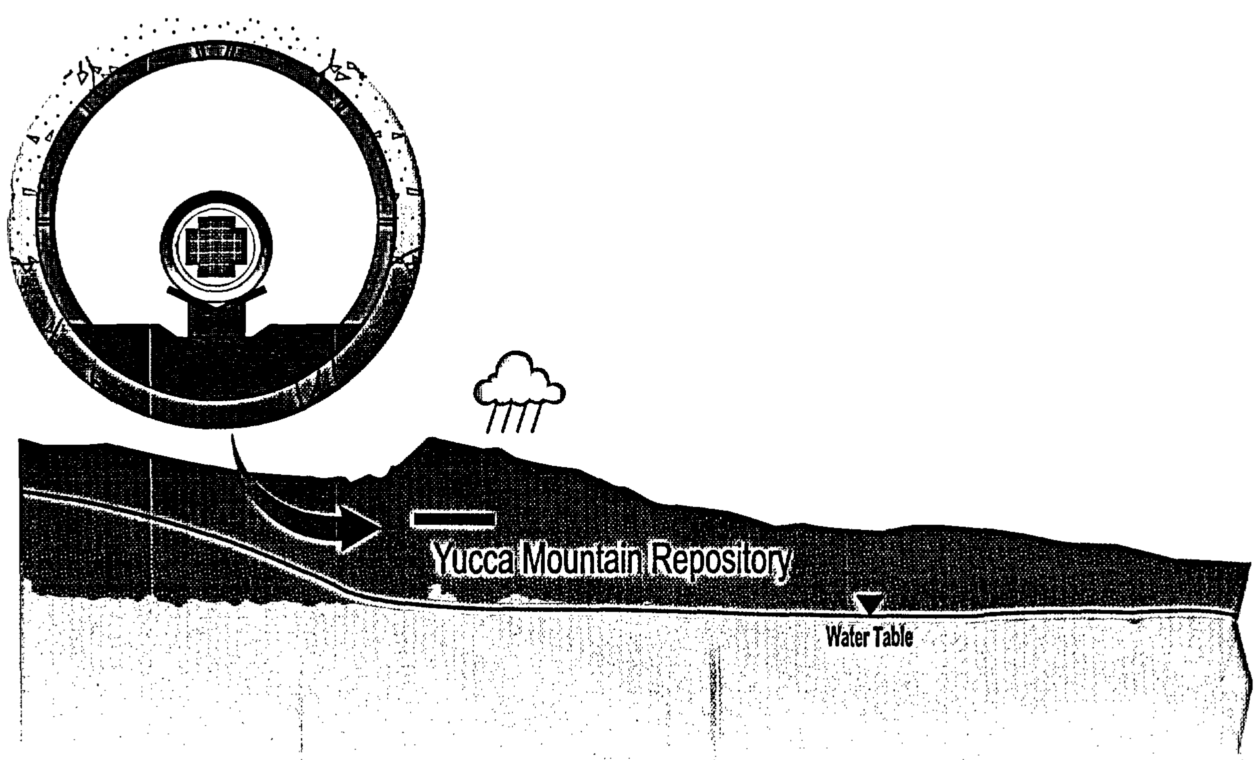
Based on preliminary results of corrosion experiments and the opinions of experts, computer simulations indicate that most of the waste packages would last more than 10,000 years, even if water is dripping on them. The longevity of man-made materials in the repository environment over such long periods of time is subject to significant uncertainty, however, and some waste packages could fail earlier. Scientists estimate that dripping water could cause the first penetrations—tiny pinholes—to appear in some waste packages after about 4,000 years. More substantial penetrations could begin to occur about 10,000 years later. Projections of waste package performance also assume that at least one waste package will fail in 1,000 years due to a manufacturing defect.

To reduce the uncertainty in waste package performance, further research on the conditions that waste packages will be exposed to and testing of waste package materials is underway. In addition, DOE is evaluating alternative waste package designs and materials that could compensate for the uncertainty and enhance longevity.

Low rate of release of radionuclides from breached waste packages

Once water enters a waste package, it would have to penetrate the metal cladding of the spent nuclear fuel to reach the waste. For about 99 percent of the commercial spent nuclear fuel, the cladding is highly corrosion-resistant metal that is designed to withstand the extreme temperature and radiation environment in the core of an operating nuclear reactor. Current models indicate that it would take thousands of years to corrode cladding sufficiently to allow water to reach the waste and begin to dissolve the radionuclides. However, estimates of cladding performance are uncertain, and more work in this area is planned.

During the thousands of years required for water to reach the waste, the radioactivity of most of the radionuclides would decay to virtually zero. For the remaining radionuclides to get out of the waste package, they must be dissolved in water, but few of the remaining radionuclides could be dissolved in water at a significant rate. Thus, only the long-lived, water-soluble radionuclides, such as isotopes of technetium, iodine, neptunium, and uranium, could get out of the waste package. Although most of the waste would not migrate from the package even if it were breached, the release of any radionuclides is reason for concern and motivation for seeking improvements in the repository design. Ongoing tests are providing more information on how radionuclides dissolve in water.



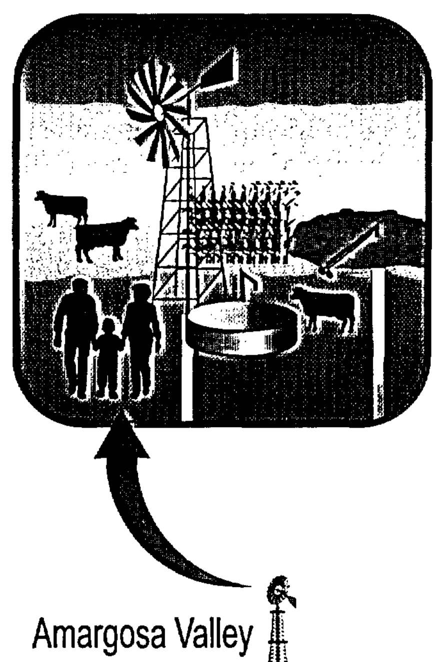
Reduction in the concentration of radionuclides as they are transported from the waste packages

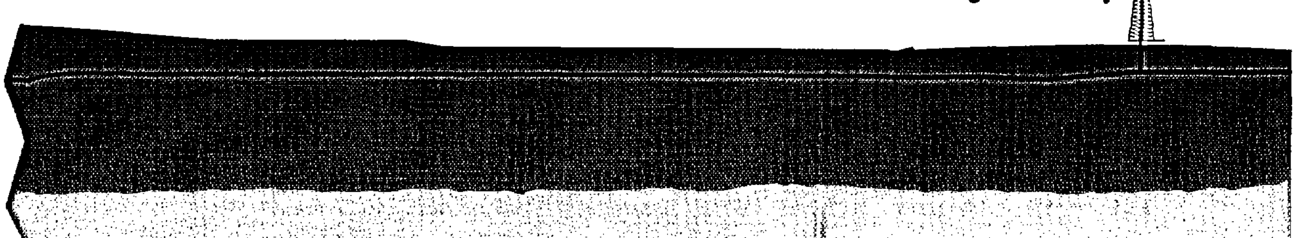
Long-lived, water-soluble radionuclides that migrate from the waste packages will have to move down through about 1,000 feet of rock to the water table and then travel about 20 kilometers (about 12 miles) to reach a point where they could be taken up in a well and consumed or used to irrigate crops.

As the long-lived, water-soluble radionuclides begin to move down through the rock, some will stick (or adsorb) to the minerals in the rock and be delayed in reaching the water table. After reaching the water table, radionuclides will disperse to some extent in the larger volume of groundwater beneath Yucca Mountain, and the concentrations will be diluted. Eventually, groundwater with varying concentrations of different radionuclides will reach locations near Yucca Mountain where the water could be consumed.

Of the approximately 350 different radioactive isotopes present in spent nuclear fuel and high-level radioactive waste, six are present in sufficient quantities and are sufficiently long-lived, soluble, mobile, and hazardous to contribute significantly to calculated radiation exposures. Four of these isotopes—technetium-99, iodine-129, neptunium-237, and uranium-234—can be transported by moving groundwater because they do not adsorb well to minerals. Two isotopes—plutonium-239 and plutonium-242—tend to adsorb but could be mobile because they can attach themselves to small particles (or colloids) and then be transported along with those particles.

Given the uncertainty about the rate at which groundwater moves and the possible existence of fast pathways or channels through the saturated zone, the DOE is continuing to investigate groundwater flow characteristics and is analyzing the possible effects on radionuclide transport and dilution.





Possible dose

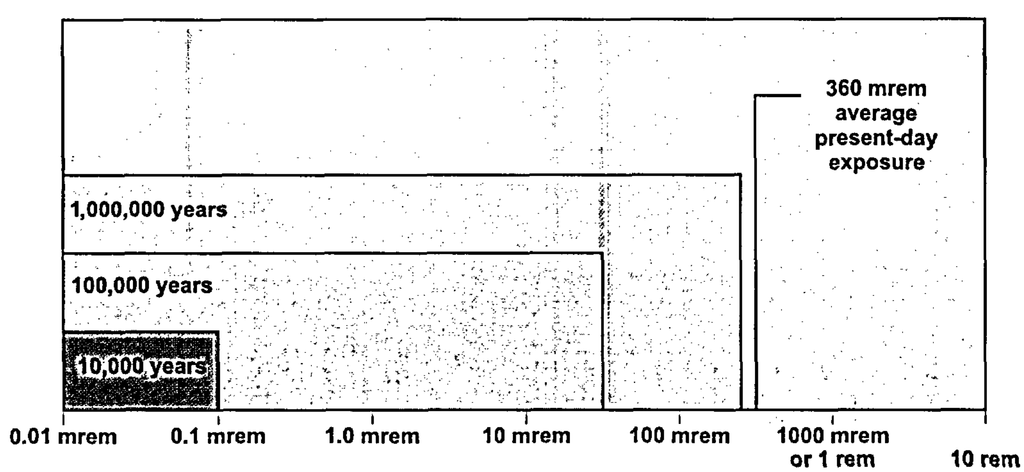
Analysts have calculated the possible radiation dose rate to people who may be living near the repository thousands of years in the future. Because where and how people will be living in the distant future cannot be predicted, analysts base their calculations on the current situation. They assume that the nearest population lives 20 kilometers (about 12 miles) from the repository boundary and has a lifestyle similar to the average person living today in Amargosa Valley, about 30 kilometers (about 19 miles) from Yucca Mountain.

During the first 10,000 years after the repository is closed, current models indicate that the mean peak annual dose rate to an average individual in this future population would be about 0.1 millirem. However, given the uncertainties associated with the assumptions and the performance assessment models, the peak dose could be higher or lower than the estimated average. There is a 5 percent (1 in 20) chance of exceeding 0.8 millirem and a greater than 25 percent chance of no exposure at all.

During the first 100,000 years, the mean peak annual dose rate to an average individual is estimated to be 30 millirem with a 5 percent chance of exceeding 200 millirem and a greater than 20 percent chance of zero dose.

Radiation is a form of energy that is everywhere in the natural and man-made world. The basic unit for measuring the damage that a given dose of radiation can cause to human tissue is called a rem. Each year in the United States, the average person receives a dose of about 360 millirem (a millirem is one one-thousandth of a rem) from natural and man-made sources. Natural sources—cosmic rays, radon gas, soil and rock, and the human body itself—account for about 300 millirem of the total annual average dose, with man-made, mostly medical, sources accounting for the remaining 60 millirem.[18] Man-made sources of radiation include diagnostic X-rays and other medical procedures, television sets, and computer monitors. Radiation exposures vary widely depending on geographic location and life choices. For example, a person living at an altitude of 5,000 feet in Denver, Colorado, receives nearly two times as much cosmic radiation as a person living near sea level in Washington, D.C.[19]

During the first 1 million years, the mean peak annual dose rate to an average individual is estimated to reach 200 millirem, with a 5 percent chance of exceeding 1,000 millirem (or 1 rem) and a 5 percent chance of being lower than 0.07 millirem.



Mean peak annual dose rate from the repository

Other safety issues

The analysis of the safety of a repository at Yucca Mountain must also consider both the likelihood and the effect of possible disruptive processes and events, such as volcanism, earthquakes, human intrusion, and "nuclear criticality." The DOE has concluded that there is little likelihood that such processes or events at Yucca Mountain would significantly affect the long-term performance of a repository.

Volcanism

The area around Yucca Mountain was very active volcanically millions of years ago. The rock of Yucca Mountain—called tuff—is composed of volcanic ash from eruptions that occurred about 13 million years ago. However, large-scale volcanism in the area ceased about 7.5 million years ago, and the last, small eruption occurred about 75,000 years ago. Experts have concluded that the chance of future volcanic activity disrupting the site is negligible. As a result, volcanism would be unlikely to affect the long-term performance of the repository.

Earthquakes

Yucca Mountain is located in the southern Great Basin, a large region that has some earthquakes. Yucca Mountain itself is a tilted block of rock that is bounded by geologic faults. A magnitude 5.6 earthquake occurred about 12 miles away in 1992. A repository and surface facilities would be designed to withstand earthquakes, as are modern tunnels, buildings, and power plants in seismically active areas.

Accidental human intrusion

It is possible that future human activities might intrude on the repository. One possible activity would be exploration for valuable natural resources. However, Yucca Mountain exhibits few characteristics that would make it an attractive location for future generations to drill or otherwise explore for gold, hydrocarbons, or other materials.

The National Academy of Sciences (NAS) concluded that there is no scientific basis for predicting such human activities over the very long periods of time for which the repository must function. The NAS, therefore, recommended that future human intrusion not be considered in the quantitative performance assessments. However, to evaluate how the repository would perform if humans were to intrude, the NAS recommended,[20] and DOE has conducted, a separate analysis of a theoretical case in which a waste package is penetrated by someone drilling into the repository in the future. Performance assessments indicate that peak dose rates would increase if a waste package were penetrated by exploratory drilling and if waste were then carried down the drillhole to the water table. However, as noted, natural resource assessments indicate that the Yucca Mountain site does not exhibit characteristics that would make it an attractive location for exploratory drilling.

Nuclear criticality

A nuclear criticality occurs when sufficient quantities of fissionable materials come together in a precise manner and the required conditions exist to start and sustain a nuclear chain reaction. The waste packages would be designed to prevent a criticality from occurring inside a waste package. In addition, it is very unlikely that a sufficient quantity of fissionable materials could accumulate outside of the waste packages in the precise configuration and with the required conditions to create a criticality. If, somehow, an external criticality were to occur, analyses indicate that it would have only minor effects on repository performance. An explosive external criticality is not credible.

What we are learning

The performance assessment shows that the most significant single factor affecting the ability of the repository to protect public health and safety would be the amount of water that directly contacts the waste. Yucca Mountain itself would provide the first major barrier to such contact, ensuring that the repository would not be flooded by either a rise in the deep water table or by infiltration of water from the surface during periods much wetter than the present. However, some waste packages will experience dripping water, and the amount is uncertain.

To address this concern, the reference design includes multiple barriers to limit water contact with the waste. The inner and outer waste package layers and the metal cladding on the spent fuel are barriers between water and the waste.

The vast majority of the radionuclides in the waste are not mobile in water and thus pose no threat to public health and safety, even when the waste package and cladding are breached and the waste is exposed to water. However, a very small fraction of the radionuclides (representing less than 0.2 percent of the initial radioactivity of all the radionuclides) are able to dissolve and move. While the quantities of the radionuclides that could reach the environment appear to be small, they nevertheless pose a potential health hazard that must be addressed.

Total system performance assessments of the reference design indicate that, for 10,000 years after the repository is closed, people living near Yucca Mountain would receive little or no increase in radiation exposure. After about 300,000 years, people living about 20 kilometers (12 miles) south of Yucca Mountain might receive additional radiation doses that are comparable to present-day doses from natural background radiation.

Although the performance assessments are encouraging, there are remaining uncertainties that should be addressed before a site recommendation decision is made and a license application is submitted to the Nuclear Regulatory Commission. Therefore, DOE plans to conduct further tests of the site and of candidate waste package materials in support of the license application. The DOE also plans to evaluate alternative repository designs that could reduce the possible doses to people living near Yucca Mountain thousands of years in the future.

Plan to complete a license application

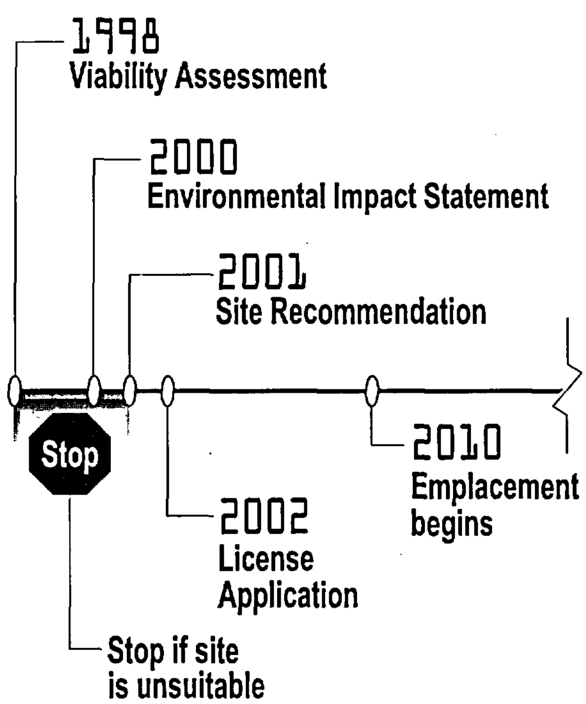
In the next four years, DOE will focus on improving the repository and waste package design, strengthening the understanding of the key natural processes, preparing the environmental impact statement, and developing the information needed to support the site recommendation decision. Because a license application takes years to prepare, DOE has begun to assemble the information needed to support one.

Before DOE can submit a license application to the Nuclear Regulatory Commission (NRC), the Nuclear Waste Policy Act requires the following decisions, any one of which can stop the process:

- The Secretary must decide, based on a formal evaluation of the site and after considering the views of States, affected Indian tribes, and the NRC, whether to recommend the site to the President. A site recommendation must be accompanied by an environmental impact statement, which is scheduled for completion in 2000. Current schedules plan for a site recommendation to be made in 2001.
- The President will then decide, possibly in 2001, whether to recommend the Yucca Mountain site to Congress.
- If the Governor and legislature of Nevada submit a notice of disapproval to Congress, Congress must then decide whether to override Nevada's objections and approve the Yucca Mountain site.

If the preceding decisions are made in a timely manner and ultimately support development of a repository at the Yucca Mountain site, DOE would submit a license application to NRC in 2002.

To obtain an NRC license, DOE must demonstrate that a repository can be constructed, operated, monitored, and eventually closed without unreasonable risk to the health and safety of workers and the public. The challenge in licensing a geologic repository is demonstrating a reasonable assurance of compliance with long-term safety standards for many thousands of years. However, the recent issuance of a permit by the Environmental Protection Agency for the disposal of long-lived transuranic waste in the Waste Isolation Pilot Plant shows that compliance with long-term safety standards is achievable. In preparing to submit a license application, DOE is drawing on the Waste Isolation Pilot Plant experience and focusing on both operational and long-term safety issues.



Operational safety

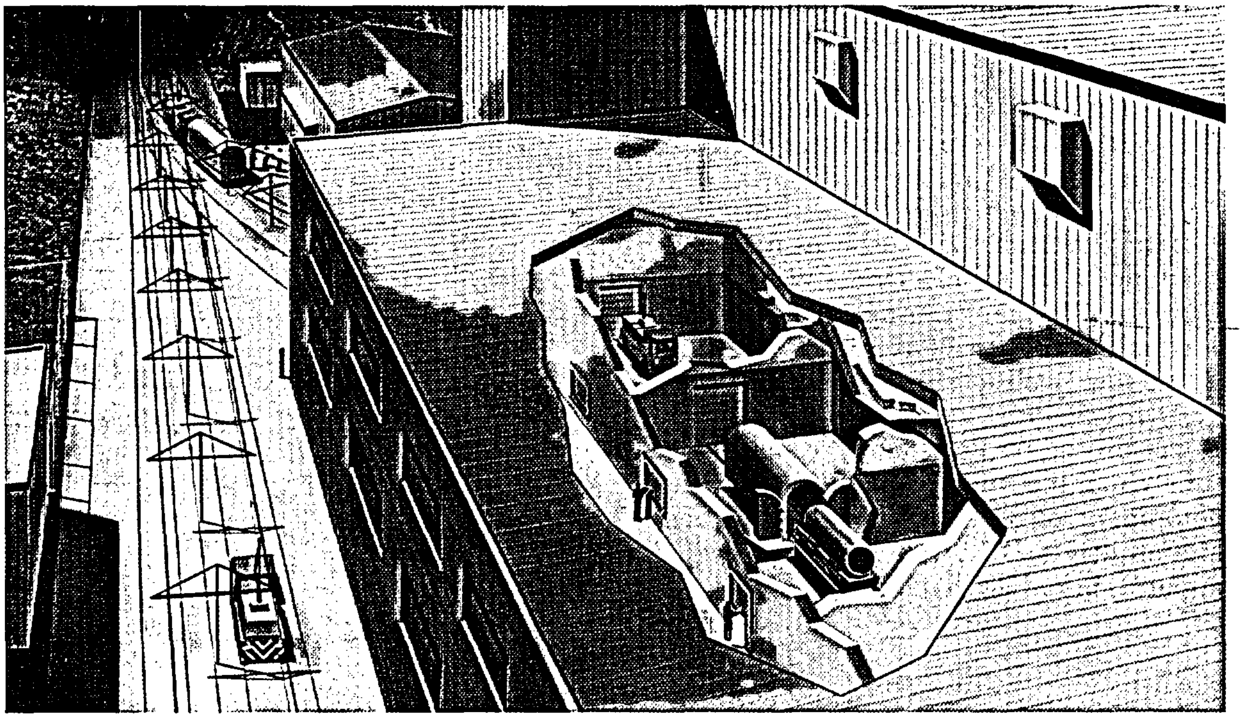
To ensure that a repository can be operated safely, DOE is using demonstrated technology and accepted design criteria, systematically identifying design-basis events, and classifying all repository structures, systems, and components on the basis of their importance to safety.

Demonstrated technology and accepted design criteria

Designing waste-handling facilities and operations is not a unique endeavor. Many codes, standards, and Nuclear Regulatory Commission regulatory guidance documents, along with many years of industry experience in the operation of nuclear facilities, can be applied to preclosure repository design and operations. (Preclosure refers to the time when waste is being emplaced and monitored.) Many elements of the reference design are based on demonstrated technology and accepted design criteria to ensure protection of both workers and the public during the preclosure period of repository operations.

Identification of design-basis events and safety classifications

Nuclear Regulatory Commission regulations require DOE to identify internal design-basis events (such as dropping a waste package) and external design-basis events (such as an earthquake) that could cause accidents resulting in unacceptable radiation exposures to workers or to the public. The regulations require that DOE protect both workers and the public when designing any engineered structures, systems, or components that are important to safety: all such elements must be able to withstand design-basis events. The DOE is now identifying design-basis events, performing safety classifications, and incorporating the resulting design requirements into its design requirements documentation.



Artist's concept of operations to move waste underground. Remote-controlled equipment would be used to place waste packages on rail cars and move the rail cars into shielded transporters. Human-operated electric locomotives would take loaded transporters underground.

Long-term safety

To reduce current uncertainties and increase confidence that a repository can contain and isolate waste for thousands of years, DOE is focusing its ongoing efforts on three major areas:

- Increasing understanding of the key natural processes that are important to long-term performance of a repository
- Improving the design of key engineered components of a repository
- Increasing confidence in performance assessment models

These three sets of activities will be the focus of DOE work between this viability assessment and the site recommendation decision, which could lead to submission of a license application.

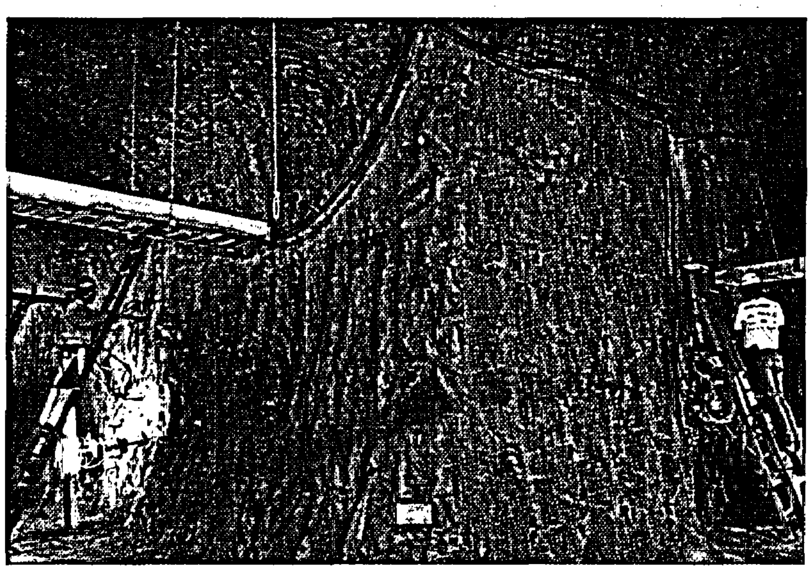
Increasing understanding of the key natural processes that are important to long-term performance of a repository

The key natural processes are water movement through the unsaturated zone above and below the repository, the effect of heat from the waste packages on moisture in the rock around the tunnels, and the movement of groundwater beneath the repository. Increased understanding of these processes will reduce the uncertainties about the performance of a repository.

The DOE is conducting experiments to determine how water could move through the unsaturated zone above and below the repository tunnels. In one experiment, water containing chemical tracers is being injected into the rock, and scientists are measuring how much and how quickly water moves through the rock. In another experiment, microspheres are being injected into the rock to simulate possible colloidal transport of radionuclides. These experiments will provide more data on how much water might infiltrate the repository and how water could transport radionuclides to the water table.

The DOE is also conducting experiments on the effect of heat generated by the waste packages on moisture in the surrounding rock. Large heaters have been placed in areas of the existing tunnel, and scientists are observing the effect of the heat on the unsaturated rock. These experiments will increase understanding of how water would be driven away from the waste packages during the period of high temperature and how, later, declining temperatures could affect water movement through the unsaturated zone.

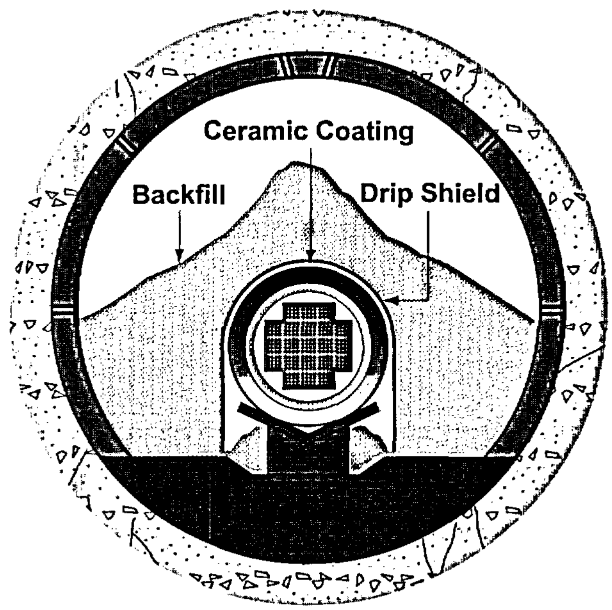
Additional information on the movement of water in the saturated zone below the water table will be gained from a series of wells installed by DOE and from wells being installed by Nye County, Nevada.



Completed single-element heater test

Evaluating ways to improve the design of key engineered components of a repository

As the design process progresses, DOE is evaluating several design options and alternatives that could reduce existing uncertainty and improve the performance of the repository system. Some of these options and alternative concepts were suggested by the Nuclear Waste Technical Review Board and by stakeholders such as the Nuclear Waste Repository Project Office of Nye County, Nevada.



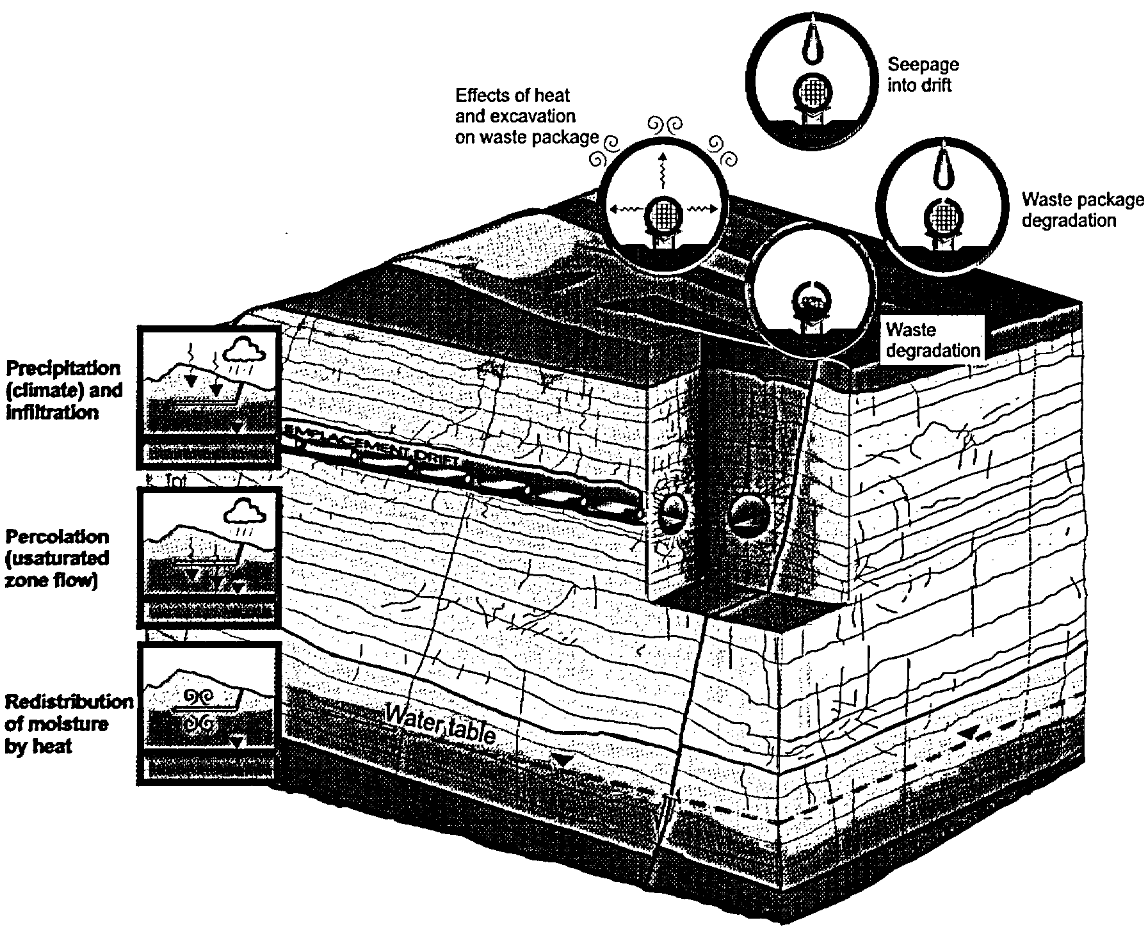
The repository design will incorporate design margin and defense in depth to increase confidence in repository performance. Design margin provides an extra margin of safety. For example, the waste package thickness could be increased to provide extra design margin. Defense in depth is intended to ensure that failure in any one barrier would not lead to unacceptable performance of the entire repository system.

The DOE will continue evaluating drip shields, ceramic coatings, and backfill options that could increase both design margin and defense in depth.

The DOE is also considering alternative repository design concepts, some of which are significantly different from the current reference design. One alternative involves a much cooler, ventilated repository design, so that moisture in the surrounding rock would never reach the boiling point. This alternative would reduce the complexity of the interaction between the natural and engineered barriers. Another alternative is to use a shielded waste package that would allow human entry into the emplacement drifts for inspection and, if necessary, remedial action.

Increasing the reliability of performance assessment models

While forecasts of repository performance over thousands of years can never be proven, laboratory and field studies and experiments provide opportunities to validate the performance assessment models. By comparing the empirical results of the experiments with the predicted results of the models, analysts can assess how well their models represent the natural processes and engineered features of a repository. Validating the performance assessment models will reduce uncertainties and increase confidence that a repository will work as expected.



Schematic cross-section of Yucca Mountain and depiction of processes that are important to repository performance

Cost of licensing, building, operating, monitoring, and closing a repository

The estimated cost to complete the repository design and other necessary work and to prepare and submit a license application in 2002 is approximately $1.1 billion, in constant 1998 dollars. This includes the costs of completing an environmental impact statement in 2000, and providing the information needed by the States, the Secretary, the President, the Congress, and the public.

The estimated cost to complete the licensing process and construct, operate, monitor, and close a repository is approximately $18.7 billion, in constant 1998 dollars. This cost estimate is based on the following assumptions:

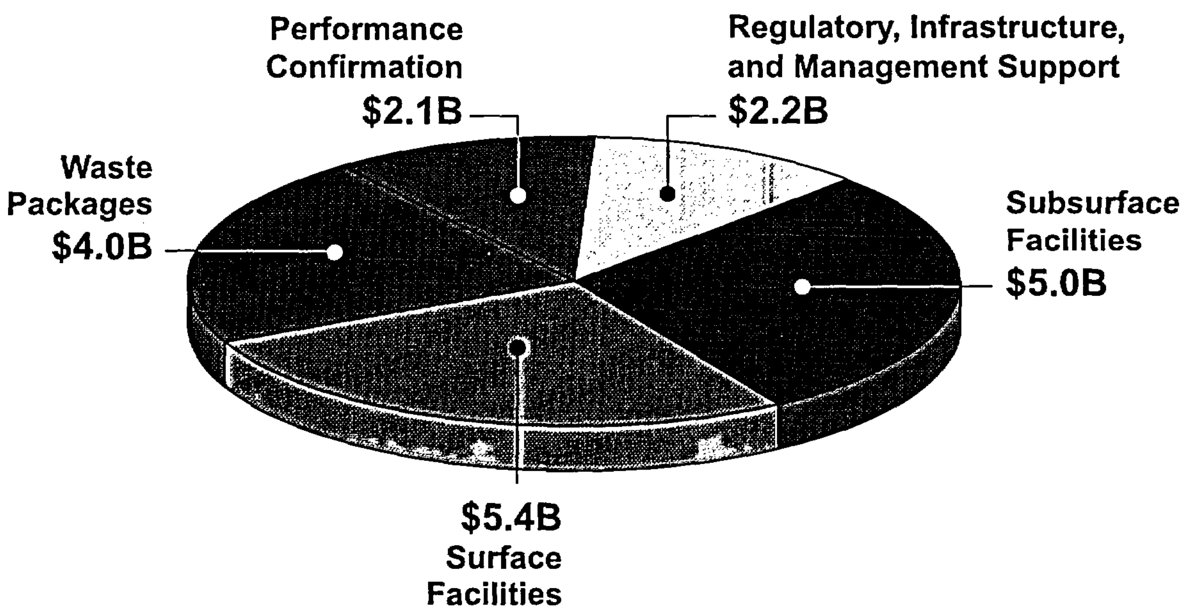
- A license application is submitted in 2002, and the Nuclear Regulatory Commission approves construction of the repository in 2005.
- Emplacement of waste in the repository begins in 2010 and ends in 2033.
- After a five-year start-up phase, commercial spent nuclear fuel is emplaced at a full-scale rate of approximately 3,000 metric tons per year.
- A total of 70,000 metric tons of waste is emplaced, including 63,000 metric tons of commercial spent nuclear fuel, 2,333 metric tons of defense spent nuclear fuel, and 4,667 equivalent metric tons of high-level radioactive waste.
- The repository remains open for 100 years after the start of operations. Closing and sealing the repository begin in 2110 and are completed in 2116.

The DOE is evaluating options for constructing and operating the repository that would reduce construction costs before emplacement begins in 2010. The surface facilities and tunnels could be constructed in phases, or modules. This modular approach could reduce annual costs but also could increase the total cost of constructing and operating the repository. These options will be evaluated in conjunction with the study of alternative designs described in the preceding section.

Repository costs

The $18.7 billion estimated repository cost reflects several factors. The repository subsurface facilities would consist of approximately 100 miles of steel- or concrete-lined tunnels, and underground operations would involve remotely operated equipment. The waste packages would be made of high grade materials and manufactured under strict quality controls and standards. The surface facilities would be designed to handle a high volume of commercial spent fuel—3,000 metric tons per year. Performance confirmation and monitoring would continue for 100 years before closing and sealing the repository.

Because research is ongoing and the repository design has not yet been selected, there is uncertainty in the cost estimate. To compensate for the uncertainty, contingencies have been incorporated into the cost estimates.



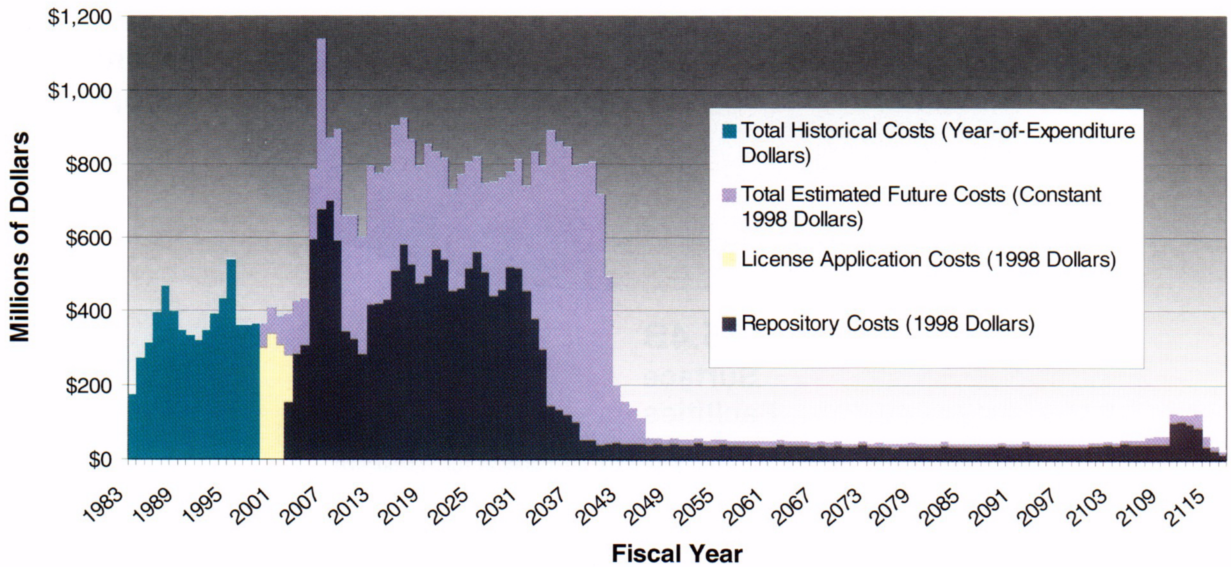
Allocation of costs to construct, operate, monitor, and close a geologic repository at Yucca Mountain

Total system life cycle costs

A monitored geologic repository is only one component of a total waste management system, which would also include overall system management, transportation, and benefits to the State of Nevada. The total life cycle costs for a complete waste management system include the following elements:

- Total program costs from 1983 through 1998 were approximately $5.9 billion in year-of-expenditure dollars. Site characterization activities at all nine of the initial candidate sites and the five-mile exploratory tunnel at Yucca Mountain account for the largest portion of the costs to date.
- The estimated costs to complete a license application and supporting documents is $1.1 billion, in constant 1998 dollars.
- The estimated costs to complete the repository design and licensing process, and then build, operate, monitor, close, and seal the repository are $18.7 billion.
- The estimated costs of expanding the repository to accommodate additional waste beyond the current 70,000 metric-ton statutory limit, if authorized, would be approximately $4.5 billion.
- The estimated costs of transporting wastes to Yucca Mountain are approximately $6.7 billion.
- Estimated payments equivalent to taxes and other benefits to the State of Nevada and affected units of local government are approximately $3.2 billion.
- The estimated costs of managing the entire system are $2.5 billion.

The total of estimated future costs is $36.6 billion, in constant 1998 dollars. (The additive total of the elements above differs due to rounding.)



Profile of total system life cycle costs. These cost estimates reflect DOE's best projections, given the scope of the work identified and planned schedule of required activities. Future events and information could result in changes to both costs and schedules. Future budget requests for the program have yet to be established and will be determined through the annual executive and congressional budget process.

C-03

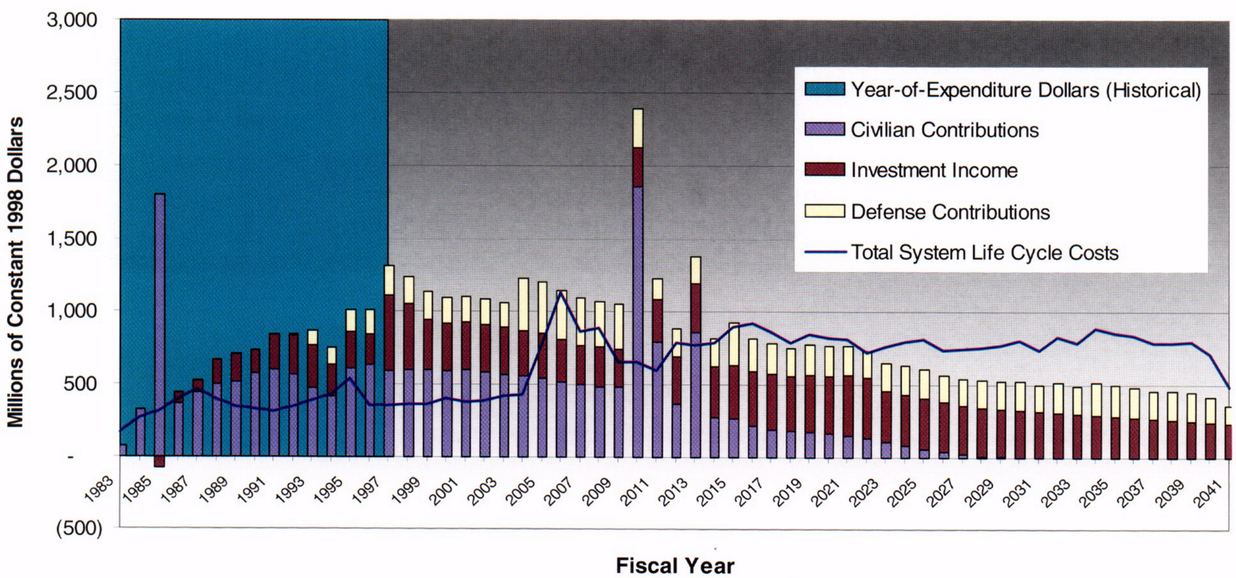
Who pays?

The Nuclear Waste Policy Act of 1982 requires entities that generate spent nuclear fuel and high-level radioactive waste to pay for the costs of disposal. The utilities with nuclear power plants pay a fee to fund the disposal of wastes from their plants, while the Federal Government uses tax revenues to pay for the disposal of radioactive waste from the nation's defense programs.

The Act directs the Secretary of Energy to enter into fee-for-service contracts with utilities for disposing of the waste. In return for this service, utilities pay annual fees that are deposited into a Nuclear Waste Fund where the money earns interest until spent. In setting up the Fund, Congress recognized that the disposal program is an extremely complex, first-of-a-kind scientific and engineering project and one that can succeed only through a sustained effort over many decades. Thus, the Fund is designed to provide the adequate, assured, and stable funding—free from normal budgetary pressures—required for such a long-term effort.

The Nuclear Waste Fund is intended to cover the entire cost of disposing of commercial spent nuclear fuel. The Secretary of Energy regularly reviews the Fund and projected costs of the program to determine whether the fees will be enough to recover the full costs. If the fees are too high or too low, the Secretary is authorized to propose any required changes.

The DOE has determined that the amount generated by the current fees, including the unspent balance and accumulating interest, is sufficient to cover the total system life cycle costs of disposing of commercial spent nuclear fuel. This assumes that the unspent balance and interest income from the Nuclear Waste Fund will remain available for their originally intended purpose.



Historical and projected program income and costs through the waste emplacement phase. These cost estimates reflect DOE's best projections, given the scope of the work identified and planned schedule of required activities. Future events and information could result in changes to both costs and schedules. Future budget requests for the program have yet to be established and will be determined through the annual executive and congressional budget process.

C-04

Concluding observations

Based on the viability assessment, DOE believes that Yucca Mountain remains a promising site for a geologic repository and that work should proceed to support a decision in 2001 on whether to recommend the site to the President for development as a repository. Over 15 years, extensive research has validated many of the expectations of the scientists who first suggested that remote, desert regions of the Southwest are well-suited for a geologic repository. Engineered barriers can be designed to contain waste for thousands of years, and the natural barriers can delay and dilute any radioactive material that migrates from the waste packages. Current models indicate that the possible radiation exposure to future populations living nearby could be comparable to present-day exposure levels from natural background radiation. Design alternatives that may improve performance and reduce remaining uncertainties are now being evaluated.

The performance of a geologic repository over such long time periods—longer than recorded human history—cannot be proven beyond all doubt. Forecasts about future geologic and climatic conditions and engineering estimates of how long the waste packages will remain intact cannot be directly validated. The mathematical models used in the performance assessment are subject to uncertainties that can be reduced but never completely eliminated.

The Nuclear Regulatory Commission's general standard for meeting geologic repository regulatory criteria and objectives is reasonable assurance. While considerable uncertainties remain today, DOE believes that reasonable assurance should be achievable in the licensing process after the planned work is completed. The DOE believes, therefore, that ongoing work at Yucca Mountain should proceed as planned.

Endnotes

The numbers at the end of each reference are Office of Civilian Radioactive Waste Management accession numbers. See the inside front cover of this document for whom to contact regarding more information.

[1] Energy and Water Development Appropriations Act, 1997. Public Law 104-206. 238115.

[2] For a description and discussion of radioactive waste and its management, see The League of Women Voters 1993. *The Nuclear Waste Primer: A Handbook for Citizens.* New York: League of Women Voters Education Fund. 210697.

[3] U.S. District Court, Utah 1995. Joint Motion for Entry of Consent Order Based on Settlement Agreement and Consent Order in the Case of Public Service Co. of Colorado v. Batt, October 17, 1995. Civil Case No. 91-0054-S-EJL (Legal Pleadings). U.S. District Court for the District of Idaho. 240346.

[4] U.S. Department of Energy 1997. *Linking Legacies: Connecting the Cold War Nuclear Production Processes to Their Environmental Consequences.* DOE/EM-0319, pp. 34-38. Washington, D.C.: DOE. 241255.

[5] National Academy of Sciences/National Research Council 1957. *The Disposal of Radioactive Waste on Land.* Publication 519, p. 4. Washington, D.C.: National Academy Press. 241256.

[6] U.S. Department of Energy 1980. *Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste.* DOE/EIS-0046F. Washington, D.C.: DOE. 205022.

[7] National Research Council 1990. *Rethinking High-Level Radioactive Waste Disposal, A Position Statement of the Board on Radioactive Waste Management,* p. vii. Washington, D.C.: National Academy Press. 241259.

[8] Nuclear Waste Policy Act of 1982. Public Law 97-425. 222165.

[9] 10 CFR [Code of Federal Regulations] 60. Energy: Disposal of High-Level Radioactive Waste in Geologic Repositories. 239474.

[10] Nuclear Waste Policy Amendments Act of 1987. Public Law 100-203. 223717.

[11] 10 CFR 60. Energy: Disposal of High-Level Radioactive Wastes in Geologic Repositories. 239474.

[12] Energy Policy Act of 1992. Public Law 102-486. 233191.

[13] National Research Council 1995. *Technical Bases for Yucca Mountain Standards.* Washington, D.C.: National Academy Press. 104723.

[14] Interagency Review Group on Nuclear Waste Management 1979. *Report to the President by the Interagency Review Group on Nuclear Waste Management.* TID-29442, p. 37. Washington, D.C.: DOE. MOL.19980625.0169.

[15] Letter from Dr. Vincent McKelvey to Richard W. Roberts, Assistant Administrator for Nuclear Energy, U. S. Energy Research and Development Administration, Washington, D.C. July 9, 1976. 238792.

[16] Winograd, I.J. 1981. "Radioactive Waste Disposal in Thick Unsaturated Zones." *Science, 212,* pp. 1457-1464. Washington, D.C.: American Association for the Advancement of Science. 217258.

[17] National Research Council 1990. *Rethinking High-Level Radioactive Disposal, A Position Statement of the Board on Radioactive Waste Management,* pp. 5–6. Washington, D.C.: National Academy Press. 241260.

[18] DOE 1992. *Science, Society, and America's Nuclear Waste, Unit 1, Teacher Guide.* DOE/RW-0361 TG. Washington, D.C.: DOE. 214909.

[19] League of Women Voters 1993. *The Nuclear Waste Primer: A Handbook for Citizens*, p. 12. New York: League of Women Voters Education Fund. 210697.

[20] National Research Council 1995. *Technical Bases for Yucca Mountain Standards*, p.12. Washington, D.C.: National Academy Press. 104273.

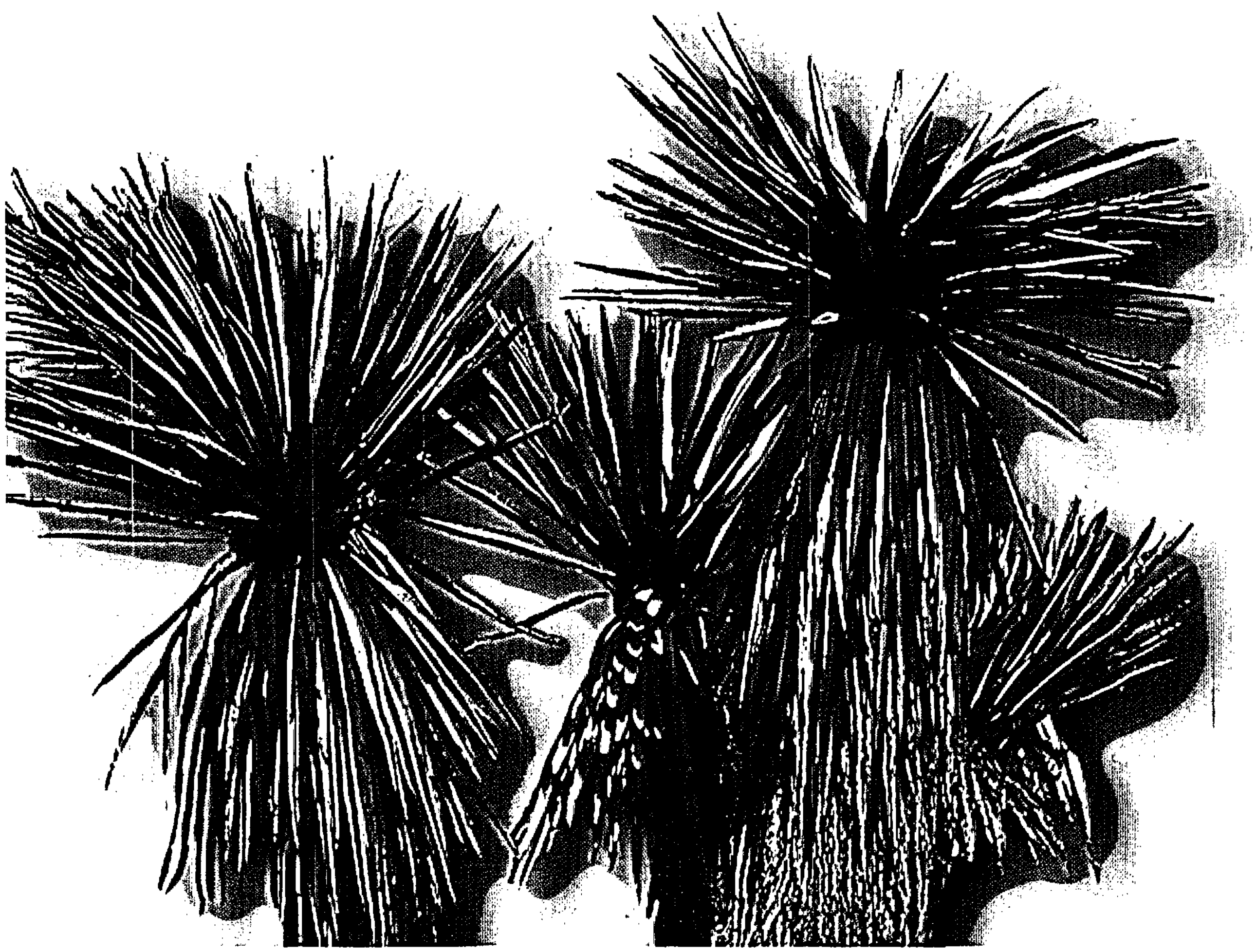
Glossary

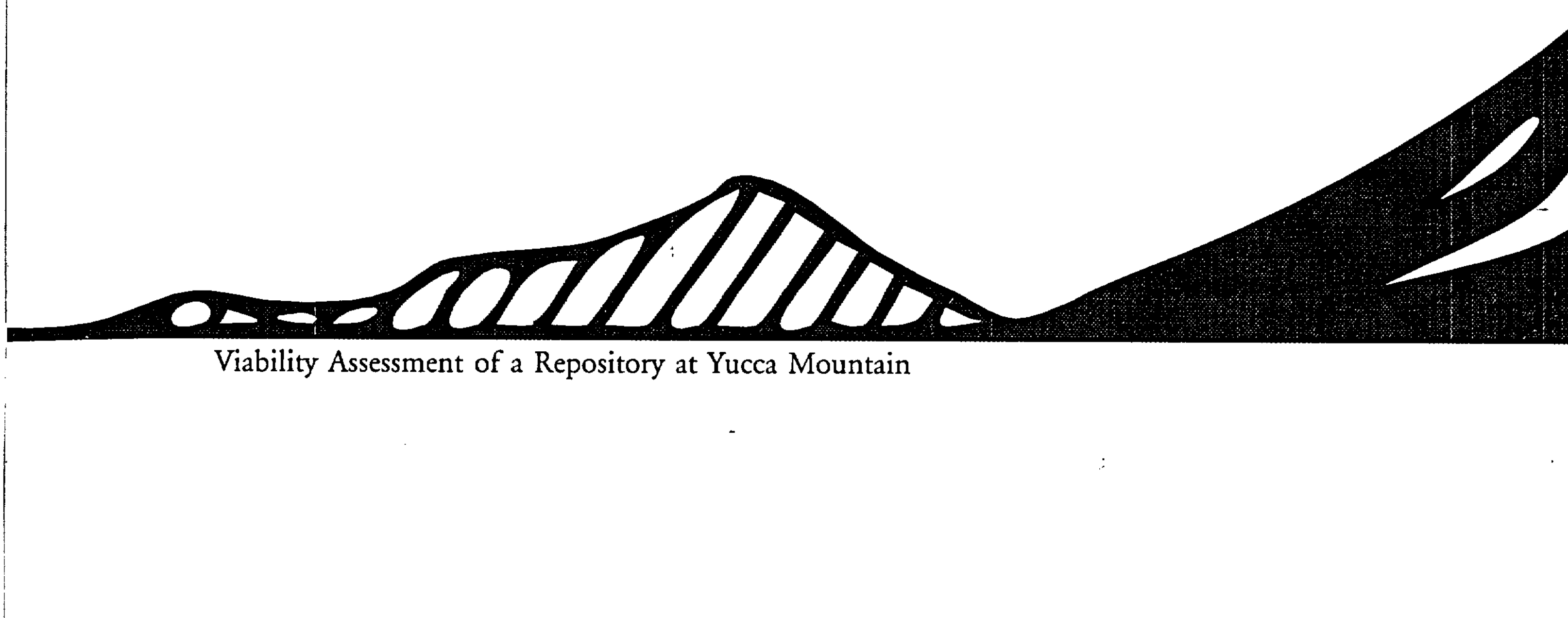
Adsorb	To transfer dissolved materials, including radionuclides, in groundwater to the solid geologic surfaces with which they come in contact.
Background radiation	Radiation arising from natural radioactive material always present in the environment, including solar and cosmic radiation, and radiation from radon gas, soil and rocks, and the human body.
Cladding	The metallic outer sheath of a nuclear reactor fuel element, generally made of a zirconium alloy. It is intended to isolate the fuel element from the external environment.
Colloid	Small particles in the size range of 10^{-9} to 10^{-6} meters that are suspended in a solvent. Naturally occurring colloids in groundwater arise from clay minerals.
Defense in depth	A strategy based on a system of multiple, independent, and redundant barriers, designed to ensure that failure in any one barrier does not result in failure of the entire system.
Design margin	Margin of safety in specifications for engineered components to account for uncertainty in the conditions to which the components will be subjected and for variability in the properties of component materials.
Dose	A quantity of radiation or energy absorbed by any material; measured in rads. Equivalent dose measures the amount of damage to human tissues from a radiation dose; equivalent dose is measured in rems.
Drift	From mining terminology, a horizontal underground passage.
Gantry	A movable crane carried on a four-legged portal frame that runs along rails.
High-level radioactive waste	Highly radioactive material resulting from the reprocessing of spent nuclear fuel. Originally produced in liquid form, high-level radioactive waste must be solidified before disposal.
Invert	(1) The low point of something such as a tunnel, drift, or drainage channel. (2) An engineered structure or material placed on excavated drift floors (the low points) to serve as structural support for drift transportation or emplacement systems.
Isotope	One of two or more atomic nuclei with the same number of protons (i.e., the same atomic number) but with a different number of neutrons (i.e., a different atomic weight). For example, uranium-235 and uranium-238 are both isotopes of uranium.
Metric ton	In this document, metric ton means a *metric ton of heavy metal.* A metric ton is a unit of mass equal to 1,000 kg (about 2,205 lb). Heavy metals are those with atomic masses greater than 230. Examples include thorium, uranium, plutonium, and neptunium.

Millirem	A millirem is one one-thousandth of a rem, which is the unit of equivalent dose. Equivalent dose is a measure of the effect that radiation has on humans. The equivalent dose takes into account the type of radiation and the absorbed dose. Rem is an initialism for Roentgen equivalent man.
Natural analog	Natural geologic systems that parallel situations that can develop in man-made systems. An example of a natural analog is the natural nuclear reactor at the Oklo uranium deposit in Gabon, Africa, which can be used as a source of analog data for conceptual models of nuclear criticality.
Non-welded tuff	See *Tuff.*
Percolate	Referring to the movement of water downward through soil and rock.
Performance assessment	An analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Repository performance assessments will include estimates of the effects of uncertainties in both data and modeling.
Radioactive waste	For the purpose of this document, spent nuclear fuel or high-level radioactive waste.
Radionuclide	A radioactive isotope.
Saturated zone	The region below the water table where rock pores and fractures are completely saturated with groundwater.
Spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
Transuranic waste	Waste contaminated with uranium-233 or with radionuclides having atomic numbers greater than that of uranium.
Tuff	Rock derived from volcanic ash. *Welded tuff* results when the volcanic ash is hot enough to melt together and is further compressed by the weight of overlying materials. *Non-welded tuff* results when volcanic ash cools in the air sufficiently that it doesn't melt together, yet later becomes rock through compression.
Unsaturated zone	The zone of soil and rock between the land surface and the water table.
Water table	The upper limit of the portion of the ground wholly saturated with water.
Welded tuff	See *Tuff.*

Acronyms

DOE	Department of Energy
EPA	Environmental Protection Agency
NAS	National Academy of Sciences
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982





Viability Assessment of a Repository at Yucca Mountain