Chapter One

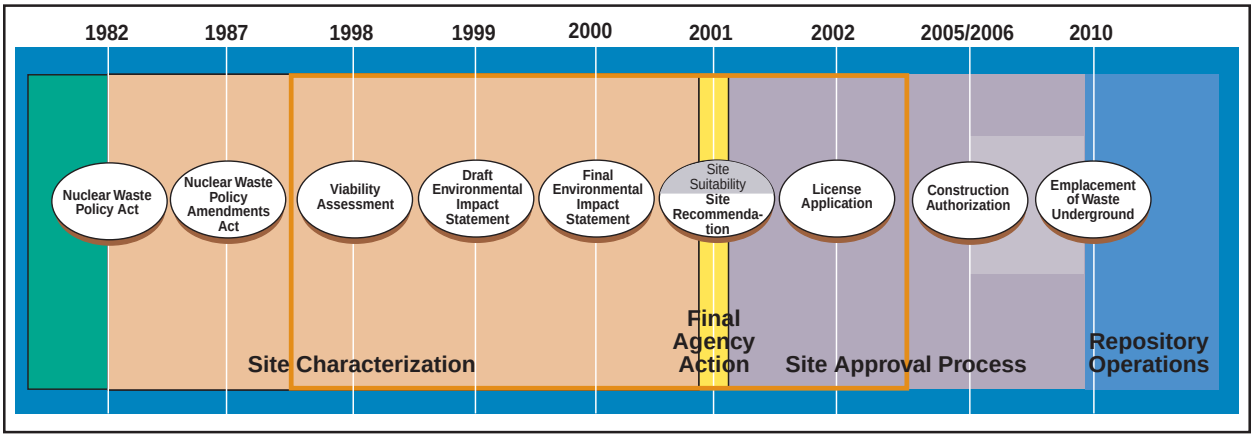
Yucca Mountain Site Characterization Project

Overview

In the Department's Fiscal Year 1997 appropriation, Congress endorsed our approach to site characterization and our plans for a viability assessment, specifying the components of the assessment and directing us to complete it by September 30, 1998. Congress also authorized all the funding for the Yucca Mountain Project that we requested—an increase of $75 million over the prior year's $250 million.

on an environmental impact statement. Coordinating closely with producers and custodians of Government-managed nuclear materials, we worked to factor data about those materials into waste package designs, performance assessments, and environmental impact statement analyses.

In addition to preparing the plan for developing a license application that is required for the viability assessment, we prepared a more-detailed, long-range licensing plan that includes a schedule, supporting



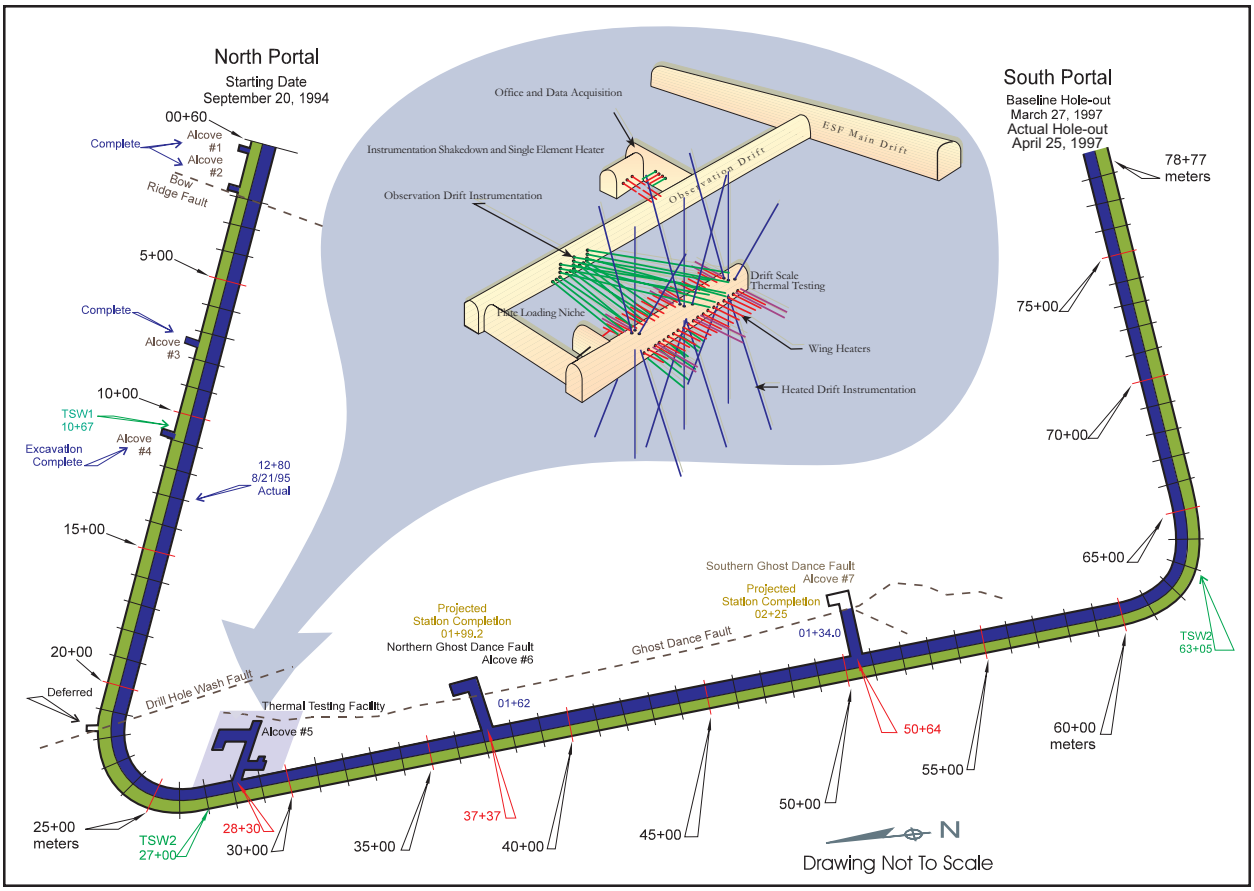
Schedule and Steps for Potential Repository Development

In keeping with congressional direction and our revised *Program Plan*, we focused on key issues related to the viability assessment and determination of site suitability. We completed the main loop of the Exploratory Studies Facility, acquired valuable data from scientific investigations, refined designs for the repository and waste package, launched a concerted effort to increase the transparency and technical validity of total system performance assessment, proposed amendments to our siting guidelines, and resumed work

schedule logic, and milestones. This plan will guide our daily work if Congress continues to support development of a repository at the Yucca Mountain site and the site is determined to be suitable. The schedule for potential repository development is depicted below.

The Project Meets a Pivotal Milestone

On April 25, 1997, we completed the 31-month excavation of the main loop of the underground



Exploratory Studies Facility

Exploratory Studies Facility. The event was of pivotal importance to the success of site characterization because this underground laboratory gives scientists direct access to the proposed repository block, enabling them to gather data that can be used to model the natural processes at the site. The models, in turn, are used to design the repository and waste packages and for assessments of the likely performance of the repository system that will support key decisions leading to and through licensing.

While scientists had been conducting underground studies in the portions of the facility already excavated, completion of the main loop gave them access to critical underground portions of the site, such as the Ghost Dance Fault, and enabled them to collect important data on movement of water and thermal stress effects within the host rock. They used these data to verify data obtained earlier from surface-based testing, strengthening predictions of the performance of a repository at the site scale.

Successful and timely completion of the main loop and of several test alcoves maintained our schedule for proposed repository development. It met a commitment made in the Secretary's Performance Agreement with the President for Fiscal Year 1997, and it met several milestones in our revised *Program Plan*. Completion of the loop also brought the Yucca Mountain Site Characterization Project the Secretary of Energy's first *Pride Award*.

A custom-built machine performs well

The 8-kilometer (5-mile) main loop was excavated with a tunnel boring machine 7.6 meters (25 feet) in diameter. Designed to meet scientific and regulatory requirements, this $13 million machine has features not

normally found on commercial equipment, including a large mapping gantry. The machine tunneled through varied geologic units and several faults. During Fiscal Year 1997, its average tunneling rate was 73 meters (240 feet) per week, and excavation set an industry record for a single day's advance for a machine this size despite encountering large areas of blocky ground adjacent to these faults. Most important, our safety record in constructing the facility exceeded the mining industry's safety performance.

With the main loop completed, the tunnel boring machine was removed and made available for sale through the General Services Administration.

Test Alcove

Because the main loop runs along the eastern side of the potential repository block and would provide access to it if a repository is constructed at the site, the tunnel was engineered to standards appropriate to the planned lifetime of the repository. Consequently, internal ground support extended the full length of the tunnel, far exceeding typical industry practices. While this increased costs, costs declined as we gained experience. The direct cost of tunneling the main loop totaled $123 million for Fiscal Years 1994-97. To increase efficiency and reduce the costs of site characterization and potential repository construction, we are applying the lessons learned from excavating the main loop to our planning for the cross-drift (a smaller-diameter, shorter tunnel), described below, and for excavation of emplacement drifts for waste packages.

We excavate more alcoves and niches to use for studies

While studies had been conducted in test alcoves within the Exploratory Studies Facility for several years, in Fiscal Year 1997, two primary test alcoves and niches were completed, and a third alcove was nearing completion. The Ghost Dance Fault is a major geologic feature just outside the eastern boundary of the repository block. The Northern and Southern Ghost Dance Fault Alcoves intersect it. Hydrologic niches enable project scientists to investigate how moisture moves through the repository block. The start of hydrologic testing in these alcoves met a milestone in our revised *Program Plan*.

The final phase of the Thermal Test Facility (Alcove 5) was completed in March 1997. This alcove is the location for the single-heater and drift-scale heater tests described below.

We accelerate plans for a smaller-diameter cross-drift

To better understand site processes and reduce uncertainties about site suitability and repository construction, we planned an integrated construction and testing program. The underground component of this program will consist of alcoves, niches, and a drift that crosses above the repository block; the surface component will consist of two deep boreholes.

The Nuclear Waste Technical Review Board had recommended that data from an east-west drift be included in a determination of site suitability. Although our original plan to construct a cross-drift in Fiscal Year 1999 supported our milestone for site recommendation, we chose to accelerate this effort by scheduling it for Fiscal Year 1998. On July 18, 1997, we provided the Board with an interim planning report on this initiative.

To determine the optimal configuration of the cross-drift and surface boreholes, we prioritized data needed to determine site suitability and selected the cross-drift configuration that would yield the most high-priority data. Top priority was assigned to understanding the vertical variability of the hydrologic character of the Topopah Spring unit. We concluded that the drift should traverse the repository block from northeast to southwest, to provide the information needed. This configuration will (1) give us access to areas underneath zones that are infiltrated, variously, by high and low levels of moisture from the surface; (2) intersect the Solitario Canyon Fault where the displacement and complexity of faulting should be optimal for study; (3) traverse all geologic subunits included in the potential emplacement horizon; (4) provide an opportunity to directly observe variations in north-to-south fracture characteristics; and (5) allow access to the Calico Hills formation at a later date, if warranted.

By further reducing uncertainties about the site, testing conducted in the cross-drift will help us better understand processes critical to site suitability and possible repository construction. We plan to use observational data gathered from within the drift to support the viability assessment.

Work Proceeds on the Viability Assessment

What the viability assessment will tell us

Assembling the viability assessment requires shaping the results of many years of work into documentation that clearly explains the site characterization project and the significance of the data we have acquired to date. The documentation will present the following:

- The preliminary design concepts for the critical elements of the repository and waste package, including a concept of operations that identifies appropriate available technologies.

- A total system performance assessment, based on the design concepts and available scientific data and analyses, that describes the probable behavior of a repository at Yucca Mountain under a range of conditions and various design options, over thousands of years.

- An estimate of the costs to construct, operate, and close a repository, based on the preliminary design concepts.

- A plan and a cost estimate for the remaining work required to complete a license application.

The information we are assembling comes from multiple sources: (1) what we have learned from years of investigating the geologic features of and natural processes at the site, (2) laboratory testing, (3) work to develop designs for engineered barriers (the waste package and repository) compatible with the characteristics of the site, and (4) assessments of the performance of the total repository system—both engineered and natural barriers and the interactions between them. Performance assessments will be based on reasonable assumptions about the range of site processes and conditions, consistent with the available data and information.

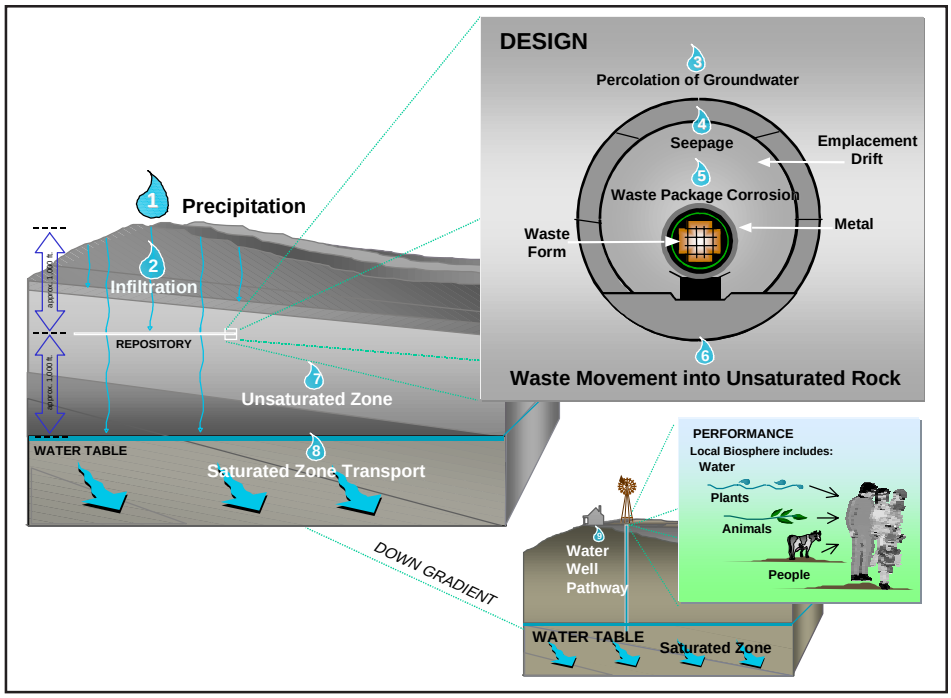
The viability assessment will inform deliberations over future program direction and funding, by helping decision-makers in the Administration and Congress understand what kind of facility can be built in this specific geologic setting, how it would perform, what it would cost to develop and operate, and what work would have to be completed to continue the process laid out in the Nuclear Waste Policy Act for submittal of a license application, should the site be found suitable.

The viability assessment is also serving as a valuable management tool by further focusing scientific investigations and design work, advancing performance assessment, and contributing to preparation of a formal site recommendation and development of an environmental impact statement and a license application.

What the viability assessment will not tell us

While the viability assessment will be a valuable product, it alone cannot support a go/no-go decision by the Department on repository development. To

determine the suitability of the site for recommendation to the President, more information will be needed from scientific investigations. And as required by the National Environmental Policy Act (NEPA) and the Nuclear Waste Policy Act, we are preparing an environmental impact statement that will inform decisions made in the determination of site suitability and the site recommendation process. The environmental impact statement would accompany a site recommendation. To prepare a license application, still more scientific investigations and detailed design work would be needed.



Multiple Natural and Engineered Barriers Working Over the Millennia

In fact, the information we assemble for the viability assessment will point to the additional work needed to support the site recommendation process and prepare a license application. Similarly, NRC comments on the sufficiency of information in the viability assessment, including our approach to licensing, will be a valuable aid to us in preparing for a site recommendation and licensing.

The role of confirmatory testing

If the program proceeds to submittal of a license application, site investigations and analyses will continue throughout repository license review and, if the repository is licensed, throughout construction and operations. The Nuclear Waste Policy Act of 1982 and NRC regulations require a performance confirmation program that uses the results of continued testing to confirm the assumptions that are the basis for the safety case that will support our license application.

In Fiscal Year 1997, we developed a performance confirmation management plan that will guide that testing program. The focus of testing will be determined largely by what the NRC says about the sufficiency of our site characterization work in its formal comments on (1) the environmental impact statement accompanying a site recommendation, (2) the site recommendation, and (3) the license application.

The Repository Safety Strategy Evolves

The purpose of a repository is to dispose of wastes in a safe and environmentally protective manner. To accomplish this, the repository must contain radionuclides for many thousands of years. Our strategy for protecting the public and the environment relies on a combination of natural and engineered barriers to first contain radionuclides within waste packages and then to limit their release and transport.

The strategy is informed by what we have learned from years of studies, investigation of the site, and work done to develop the engineered system. Our understanding was enhanced by the total system performance assessment iterations completed in 1991, 1993, and 1995, and by considerable recent design work.

The strategy rests on working hypotheses that we can test to assess how a waste isolation system at Yucca Mountain will perform. Formulated from information that had already been collected about the site, they relate to specific attributes of the natural system, as well as to specific physical characteristics of materials that may be part of the engineered system, and to the important interactions between the natural and engineered systems. The hypotheses enable us to design the engineered barriers that can augment the features of the site in retarding radionuclide migration. Taken separately, the hypotheses provide the bases for organizing, managing, and explaining the rationale for the work that will lead to a determination of site suitability. Together, they constitute a conceptual framework for rigorously assessing the waste isolation capability of a repository at Yucca Mountain.

In Fiscal Year 1997, we refined the strategy we had issued in 1996 to take into account recent information on site conditions, new repository and waste package designs, updated performance models and predictions, and expected changes in the regulatory framework. The updated strategy relies on four assumptions that are expected to be the basis for the safety case that will support our license application to the NRC:

- The amount and distribution of moisture coming into contact with the waste packages will be limited.
- The period of radionuclide containment by the waste packages will be long.
- The rate of radionuclide release from the waste packages following loss of containment will be slow.
- The concentration of radionuclides in groundwater where compliance must be evaluated will be low, due to natural processes that delay transport or lower the concentration as a result of dispersion or dilution.

The strategy enables us to concentrate our efforts on a more limited testing program to answer questions about a small number of specific hypotheses that may be crucial to the viability assessment. Using our knowledge of the site, our designs for engineered barriers, and our understanding of sensitivities indicated by total system performance assessments, we evaluated each of these assumptions and identified particular aspects of each that raise uncertainties that (1) are significant to a judgment about safety, and (2) can be mitigated through additional work. This information will shape our future testing, design, and analysis plans.

We presented briefings on the strategy to the NRC, its Advisory Committee on Nuclear Waste, and the Nuclear Waste Technical Review Board. The updated strategy, to be termed a repository safety strategy, will be issued in 1998.

Scientific Studies Further Our Understanding of the Site

Congress directed us to focus on technical issues that must be resolved to determine site suitability. Our site investigations are designed to yield data that we can use to test the four basic assumptions of our repository safety strategy by modeling the contributions to the performance of the total repository system that would be made by each of the engineered and natural barrier systems.

What we studied in Fiscal Year 1997: focusing on open issues

Site investigations are organized along lines of inquiry designed to further our understanding of individual and coupled natural processes at the site: for example, hydrological, geological, geochemical, and geomechanical processes related to stratigraphic zone stability and moisture migration under ambient and elevated temperature conditions. The lines of inquiry we pursued in Fiscal Year 1997 were the following:

- *Hydrologic studies*: percolation flux through the repository block, groundwater flow in the Yucca Mountain area, infiltration and percolation of precipitation, the characteristics of the aquifer, the presence of chlorine-36 at different locations, and the nature of groundwater chemistry
- *Geologic studies*: heterogeneity of the repository block and geologic structures such as faults and fractures, fracture frequencies, and fracture apertures

- *Geochemical studies*: effects of repository construction on natural barriers, effects of heat from waste packages and of water chemistry on the engineered barriers, and pathways and mechanisms of radionuclide transport through the natural barriers

- *Geomechanical studies*: in situ properties of the host rock, such as rock hardness, geologic structures, distribution of faults, and response of the host rock to stress and heat

How and where we gathered data

Site investigations are also organized in terms of how and where we gather data. A variety of methods are used and, because the site is not homogeneous, *where* we gather data is important; we want samples and test data to be as representative of key features as possible.

During Fiscal Year 1997, field and laboratory data were collected from a variety of sources: surface and subsurface drilling operations, routine water-level measurements of monitor wells, aquifer pumping tests, laboratory analysis of water samples, and laboratory analysis of drilling cores. Once instrumentation for continuous tests was installed, to ensure data quality, scientists, engineers, and technicians engaged in around-the-clock maintenance, testing, data collection, and monitoring. Building on prior years' work, the testing program involved the following:

- **Surface-based testing** focused on obtaining a variety of hydrologic and geologic information from boreholes and surface access test locations. Field-scale studies of groundwater flow and radionuclide dilution and sorption are conducted at the C-well complex; water elevation and water chemistry properties are measured through a network of surface-drilled boreholes. Surface-based testing is important for determining the potential for transport of radionuclides in the saturated zone. A large-block thermal experiment, described below, is being carried out at Fran Ridge.

- **Underground testing** focused on geologic, geomechanical, and geochemical data obtained in the Exploratory Studies Facility test alcoves and niches. With completion of the main loop of the facility, we were able to complete conversion of important test locations from construction sites to fully operational underground laboratories. Conversion of the main loop involved constructing and instrumenting one alcove for a long-duration, drift-scale thermal test; two alcoves for hydrologic and geologic tests in the Ghost Dance Fault; and two niches for a study of percolation flux. We also drilled many underground core and instrument test holes. From within the main loop, test alcoves, and niches, we observed key site features and collected critical site-specific data.

Strat-o-Master Drill Rig at the C-Well Complex

- **Off-site laboratory testing** focused on strengthening our understanding of the near-field environment that would surround the engineered barrier system. The question of how heat emitted by waste would affect radionuclide migration to the accessible environment was of key importance. Tests were conducted by scientists and technicians from the U.S. Geological Survey and several national laboratories, including

Water: Resolving a Key Issue for Site Suitability

The repository's engineered barriers, together with the geologic features and natural processes of the site, must retard the release of radionuclides to the accessible environment for thousands of years. The likeliest medium by which radionuclides could be transported is water, and Yucca Mountain was selected as a candidate repository site in part because it is in an arid environment.

But over geologic time, will it be arid enough? Over thousands of years will enough moisture be present to corrode waste packages and transport radionuclides? How much water percolates through the mountain? By what pathways does it travel? How much might reach waste packages, and for how long could it be in contact with them? At what rate would it corrode them? How might water transport radionuclides to the accessible environment? In what quantities and concentrations? How fast?

The fact that so little moisture is present at the site makes the task of investigating it difficult, but we carefully pursue a number of inquiries, that together help us better understand this key issue:

- Infiltration and percolation of moisture from the surface of the site. We are determining quantities, rates, and variations through space and time.
- Chlorine-36, a product of atmospheric nuclear testing in the 1950's. We are determining what its presence in elevated concentrations in rock samples can tell us about preferential pathways by which water might travel.
- Ghost Dance Fault. We are investigating whether it offers pathways by which radionuclides can travel to the accessible environment.
- Thermal loading. Heater tests help us determine the optimal temperature for the repository at any given time and what the effects of heat are on the host rock, on moisture, and on waste package materials.
- Climate. We are examining how changes in future climate could impact the site.
- Hydraulic gradient. We are investigating the nature and implications of the steep gradient in the water table north of the proposed repository site.
- Radionuclide transport. We are investigating possible mechanisms and pathways.

What we learn about the potential for moisture at the site has consequences for waste package design, helping us determine what materials the waste package should be made of and how robust it should it be. It also helps us evaluate other options for design of the waste package and of the area in which waste packages will be emplaced.

Using performance assessment, we can couple what we learn about the site with design assumptions to simulate repository performance over long periods of time.

Lawrence Livermore, Lawrence Berkeley, Argonne, Sandia, and Los Alamos. Tests examined the effects that heat may have on the basic behavior of moisture in the potential repository rock, on the chemical properties of water within the host rock, and on candidate waste package materials—and how those effects, in turn, might affect the performance of the engineered barrier system. Tests also examined how radionuclides might be transported through the natural barriers of the site.

Special focus: thermal studies

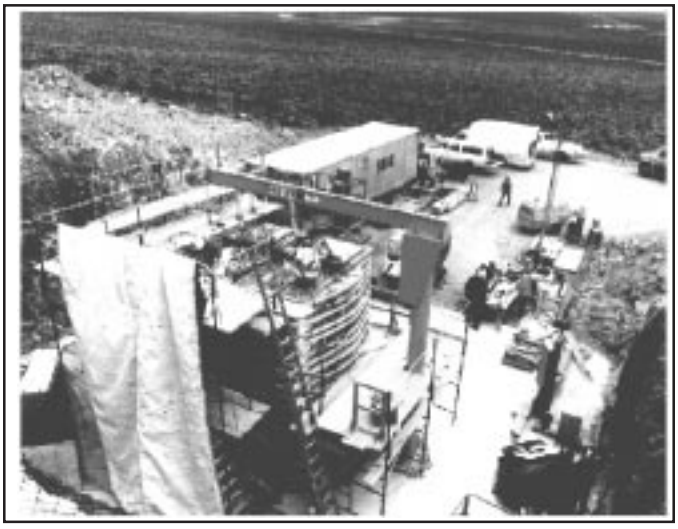
Heat emitted by radioactive waste will affect rock mineralogy, rock mechanical properties, both rock and water chemistry, site hydrogeology, and, consequently, the repository's total performance. To determine the effects of cycles of heating and cooling, we designed three studies that use electric heaters to simulate heat emitted by high-level radioactive waste. Data are collected and analyzed as the rock heats up and are collected for analysis as the rock cools down.

The first study, a large-scale underground experiment, used a single heater approximately 5 meters (16.4 feet) long to heat a 25-cubic-meter (883-cubic-foot) volume of rock to a temperature of 100 degrees Celsius; more than 300 thermometers distributed throughout the test alcove are measuring the effects. We turned the heater on in August 1996 and off in May 1997. The test results provide unique preliminary data for performance assessment calculations and technical guidance for conducting the third thermal study.

A second study involves heating a large block cut from a rock outcrop at Fran Ridge, the same geologic formation as the potential repository. This discrete above-ground block permits us to closely control and monitor the heater test parameters. The heater for this test was turned on in February 1997; the heating phase is scheduled to continue through the first quarter of 1998. Preliminary data have provided valuable information on water movement, evaporation, and condensation.

The third study, one thousand times larger in volume than the single-heater test, is the largest underground thermal test ever conducted. To provide information on a scale more representative of the repository, it will simulate a portion of an actual waste emplacement tunnel: the Thermal Test Facility, an alcove nearly 305 meters (1,000 feet) below ground and approximately 48 meters (157 feet) long, will be heated continuously over several years. The heat-up period is approximately 4 years; the cool-down period is approximately 4 years from the date the power is turned off.

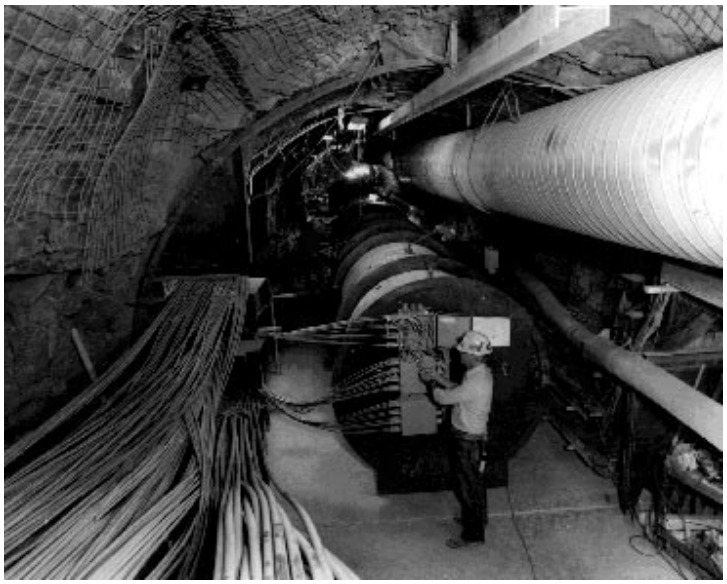
In Fiscal Year 1997, we finished excavating the test alcove. Electric heaters were placed directly in boreholes drilled into the walls of the alcove and on the floor in canisters similar in dimensions and materials to actual waste canisters, and other test instrumentation was installed. A milestone in our revised *Program Plan* called for the heaters to be turned on in Fiscal Year 1997, but as planning evolved, it became apparent that the start-date should be rescheduled to December 1997 to accommodate a larger scope of work.



Large Block Heater Test

Collaboration and peer review

We continued to collaborate with scientists at the Nevada Test Site to combine our three-dimensional, regional groundwater flow computer model with theirs. This collaboration will eventually result in a model that contains more data and can more accurately predict groundwater flow on and near the Nevada Test Site and Yucca Mountain.



Thermal Test Facility

We initiated a peer review of the results of laboratory analyses of chlorine-36 and other isotopes to ensure that our sampling, analyses, and data interpretation of groundwater pathways and associated percolation fluxes were consistent with the understanding of the scientific community outside the program. We continued to routinely seek reviews of project reports by experts who are not directly involved with the project, such as scientists from Atomic Energy of Canada Limited.

What we learned in Fiscal Year 1997

The scientific data we gathered significantly reduced uncertainties associated with the models and model predictions that will be incorporated into the total system performance assessment that will support the viability assessment. The data (1) increased our understanding of how water moves through the mountain and how heat affects its chemical composition, (2) increased our understanding of how surface infiltration influences percolation fluxes at the potential repository horizon, and (3) reduced uncertainty in modeling the natural processes that affect the engineered barriers and radionuclide transport.

We produced a report describing our current understanding of the coupled thermal, hydrologic, chemical, and mechanical processes likely to operate in the repository and the surrounding rock environment. Using additional field data, we revised our integrated site model, which allows us to examine how geologic controls at the site could influence repository performance under varying conditions.

We identified future climate scenarios and completed water flow and radionuclide transport models for the saturated and unsaturated zones, thus meeting two milestones in our revised *Program Plan*. Model simulations predicted that if the climate at Yucca Mountain becomes significantly wetter in the future, the water table under the mountain could rise 60 to 150 meters, a level still well below the level of the proposed repository. Using the flow and transport models in conjunction with the future climate scenarios, we concluded that the amount of precipitation that percolates beneath the layer of vegetation at the site may be higher in some places than previously estimated. The amount varies widely all over the mountain; the high end of the range for percolation rates is believed to be less than 20 millimeters per year; the average is believed to be less than 5 millimeters per year.

As we continue to gather more hydrologic and geochemical data from our site investigations, we will be able to further refine our radionuclide transport models.

Beyond the viability assessment, future site investigations will aim to further reduce uncertainties surrounding parameters with the greatest impacts on repository design and on the total system performance assessments that are needed to support a site recommendation, license application, and subsequent confirmatory testing.

Design Work Advances

Our approach to design

In an optimal system, the natural barrier provided by the site itself and the engineered features of the repository together will achieve performance goals. The features and natural processes of the site are a given

that cannot be significantly modified, but engineered barriers, which include the waste package and underground and surface repository facilities, can be designed in many ways. Consequently, they offer many opportunities for increasing confidence in total system performance, and we employ a rigorous approach to design to ensure that we optimize them.

Considerations of safety, performance, operations, and cost and schedule control govern design. To achieve safety and performance goals, we rely on multiple physical barriers that possess diverse physical properties that would exhibit diverse failure modes over a wide range of repository conditions. To develop designs, we (1) identify and characterize potential design features, (2) systematically evaluate repository performance using combinations of those features, (3) select sets of features that together will exceed performance requirements, (4) assess uncertainties associated with each set by conducting analyses and sensitivity studies, (5) select an appropriate set, and (6) confirm that its expected performance has an adequate safety margin.

The importance of examining alternatives

Sound engineering proceeds by examining design alternatives, and NRC regulations require us to demonstrate consideration of design alternatives in our license application. Moreover, the Nuclear Waste Technical Review Board has recommended that we develop and examine reasonable design alternatives to achieve better repository performance. Accordingly, much of our design work involves trade-off studies that evaluate competing design alternatives.

To ensure that the waste management system will perform as intended and operate smoothly, its components must be closely integrated—a point that the Nuclear Waste Technical Review Board has long stressed. Systems studies are an essential tool for examining how a design change in one component of the system may affect others. By conducting design and systems studies, we methodically narrow and eliminate technical uncertainties associated with assumptions in the system's requirements baseline. The results support recommendations for design features that can improve repository performance, reduce cost, and accelerate schedule.

Design as a dynamic process

Throughout repository development, new information—from confirmatory testing, scientific and technological advances, operational and cost considerations, the demands of the licensing process, or other sources—will continue to arise. Accordingly, we are designing the engineered system to be flexible enough to accommodate changes warranted by new information and to permit consideration of alternative engineered components and design options that could enhance confidence in overall repository system performance.

We will continue to identify and evaluate different combinations of components and design options to determine their potential contribution to overall system performance, and design may evolve even after the repository has been licensed.

Design work in Fiscal Year 1997

Design work in Fiscal Year 1997 directly supported the viability assessment: we developed reference designs for the repository and waste package that will serve as the basis for cost estimates and total system performance assessment. The reference design will consist of the features and concepts that will provide us with a reasonable estimate of repository performance based upon the best available scientific, engineering, and cost and schedule analyses.

During the year, we investigated numerous design issues. Preparation of Phase I designs for the waste package and the repository surface and subsurface facilities included development of drawings, analyses, and documentation. Completion of these designs met a milestone in our revised *Program Plan* and kept us on track toward completion of the viability assessment.

Coordination with producers and custodians of Government-managed nuclear materials

Emplacing Government-managed nuclear materials in the repository requires analysis of how they might affect repository design and performance. At our Yucca Mountain Site Characterization Office, we worked closely with producers and custodians of those materials to obtain and analyze information needed for

waste package and repository design, performance assessment, and environmental impact analyses.

Those parties are (1) the Office of Environmental Management, which manages DOE spent nuclear fuel and high-level radioactive waste; (2) the Office of Fissile Materials Disposition, which manages surplus weapons-grade plutonium; and (3) the Office of Naval Reactors, which manages Naval reactor spent nuclear fuel. To facilitate close coordination, liaison personnel from the Office of Naval Reactors and Idaho Engineering and Environmental Laboratory National Spent Nuclear Fuel Program were stationed at the Yucca Mountain Site Characterization Project.

With the Office of Environmental Management, we planned a multi-year program that will enable us to smoothly manage our technical interface. Our work plan includes provision of specific data about the quantities and characteristics of their waste forms, which are needed for design and performance assessment; provision of data about the sizes and characteristics of bare and canistered spent nuclear fuel and high-level radioactive waste; and determination of how their waste forms will be received at the repository. Another important task is ensuring that decisions the Office of Environmental Management makes about how to package its spent nuclear fuel for near-term storage will be compatible with our long-term licensing requirements.

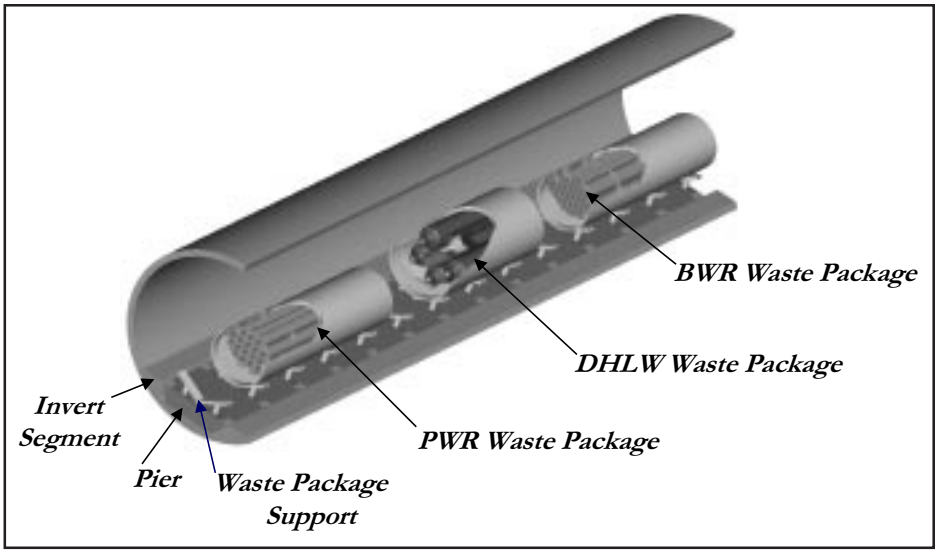
Our scoping analyses of the impacts on design and performance assessment of integrating proposed surplus weapons-grade plutonium waste forms into the waste management system supported a decision to prepare a formal change proposal to incorporate them into the baseline. We identified tasks needed to demonstrate that disposal of DOE spent nuclear fuel, high-level radioactive waste, and surplus weapons-grade plutonium waste forms will meet NRC licensing requirements, and we began some criticality analyses to evaluate how these wastes might affect the repository system's long-term performance. Because criticality analyses for Naval spent nuclear fuel involve classified information, the Navy will perform its own criticality analyses and present them directly to the NRC.

Collectively, these efforts should ensure that the impacts of integrating these materials into the waste management system are well understood and adequately accommodated.

Waste package design

Under existing NRC regulations, the waste package must provide substantially complete containment of radionuclides for a period of 300-1,000 years. We are working toward a performance goal that would leave 99.9 percent of the waste packages intact after 3,000 years. In Fiscal Year 1997, waste package design efforts included the following:

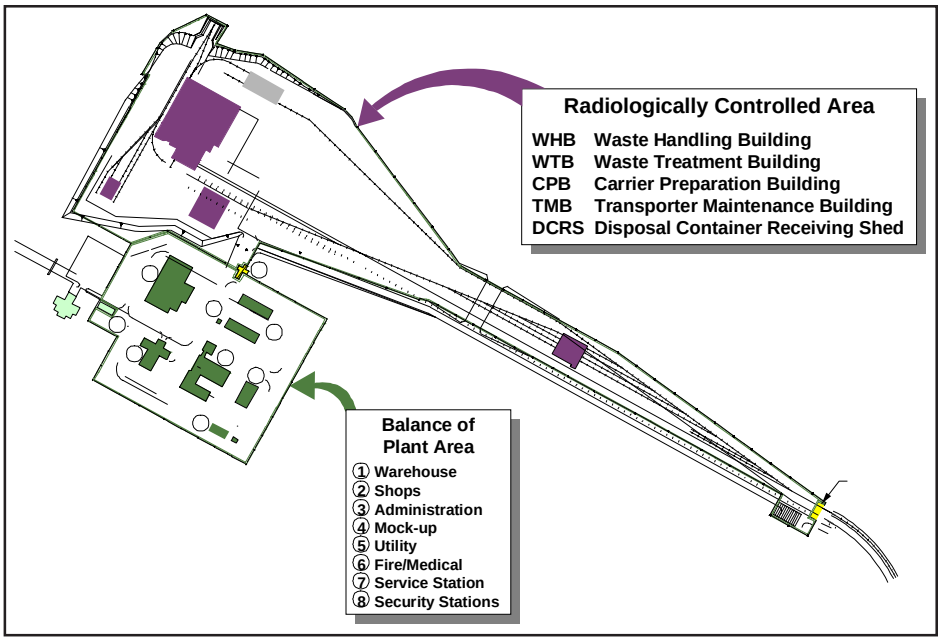
- *Corrosion/materials testing*. Materials for the waste package will be selected on the basis of their resistance to corrosion, cost, and ease of fabrication. To narrow the list of candidate materials and to reduce uncertainties associated with design, we continued to conduct corrosion tests and to model how well various materials might perform. The package is designed with a



Schematic of Waste Package

two-layer containment barrier. Materials tested for it included carbon steel and alloys of nickel, copper, and titanium; materials tested for the inner basket included borated stainless steel and carbon steel.

- *Commercial spent nuclear fuel.* Through a literature search, we compiled the dimensions and weights of the various types of commercial spent fuel assemblies. These data were used to confirm that the waste package cavity lengths and basket cell widths for uncanistered commercial fuel waste packages are satisfactory.



Drawing of Surface Facilities

- *Determination of waste package design configuration.* An analysis was performed to determine the most cost-effective method for disposing of commercial spent nuclear fuel based on thermal and criticality goals. We found that to dispose of 100 percent of commercial spent nuclear fuel, more than one distinct type of waste package design is required.

- *Criticality studies* analyzed the criticality potential arising from the disposal of spent nuclear fuel. These studies narrowed the uncertainty in determining the probability of criticality for commercial spent nuclear fuel and determined what kinds of configurations will preclude criticality.

- *Additional barriers*. Analysis of the effects and benefits of including additional barriers as part of the waste package engineered barrier system considered options that included an integral drip shield, separate drip shield, and backfill.

Surface design

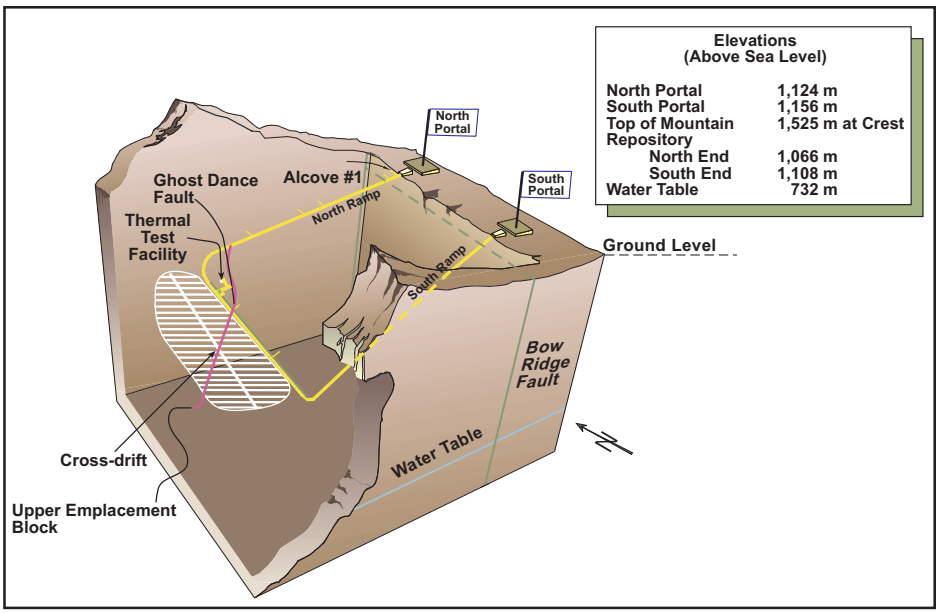
- *Site layout*. We developed a site layout that establishes the arrangement of the surface facilities, the yard, drainage and utilities. Evaluations of the Waste Handling Building, the Waste Treatment Building, and the Carrier Preparation Building included determining layouts, space and structural requirements, ventilation, and radiation protection requirements.

- *Waste handling systems.* Of major importance to repository operations are the waste handling systems, which will receive, transport, and prepare for emplacement very large casks and waste packages. The canister transfer system analysis identified the systems needed in the Waste Handling Building to remove disposable canisters from transportation casks, transfer them into disposal containers, and prepare them for transport to the underground repository. Analysis of the waste handling facilities also identified and evaluated potential operational failures in the waste handling surface facilities, and it recommended procedures and equipment needed for recovery operations.

- *Waste treatment system*. Within the Waste Treatment Building, the waste treatment system will include the primary systems required to process site-generated radioactive waste. An analysis defined the major equipment and sequence of movement required to process low-level radioactive waste.

Subsurface design

- *Repository capacity*. We defined the volume of rock mass that would be available for siting subsurface facilities, and we designed the subsurface layout and configuration of repository openings to accommodate the up-to-70,000 metric tons heavy metal (MTHM, a measure that includes uranium, plutonium, and thorium) that can be disposed of in the repository under current law. This layout offers the flexibility to modify design in order to take advantage of new information.



Drawing of Subsuface Layout

- *Ventilation and dust control requirements* were established, based on regulatory guidelines.

- *A Design Guide* was developed for designing ground support for emplacement drifts and openings, including requirements for the concrete mix for the emplacement drift permanent lining.

- *Waste package handling equipment and a viable handling concept* were developed for transport and emplacement of various waste package sizes. The waste emplacement system will transport loaded and sealed disposal containers from the surface Waste Handling Building to the waste emplacement area. This system will operate on the surface of the site between the Waste Handling Building and the North Portal, and in the underground ramp, main, access, and emplacement drifts.

- *Remote operation and control* of key subsurface waste handling and repository monitoring activities are required because of the high radiation fields and elevated temperatures near waste packages. Based on a series of preliminary design analyses and a review of available remote control technologies, several key concepts were identified for waste package emplacement and retrieval equipment and for performance confirmation. Methods for monitoring and controlling the operation of mobile equipment were identified.

- *Thermal loading*. Waste packages will emit heat, and the more densely they are emplaced in the repository the higher the temperature will be. The term *areal mass loading* refers to how densely they are emplaced, and is defined in terms of MTU per acre. High areal mass loading could reduce the repository's size and cost. The higher temperatures could keep moisture away from the waste packages for a longer period of time. However, as is usually the case in design,

there are trade-offs. To avoid design problems that could result from too high an areal mass loading, we established design limits in our thermal analyses that (1) prevent damage to the cladding on spent nuclear fuel rods, thus maintaining a barrier to the release of radionuclides; (2) protect the ability of zeolites below the repository block to absorb and retard the passage of some radionuclides released from the waste packages; and (3) prevent damage to the concrete-lined walls of the repository tunnels. We are still evaluating many aspects of thermal loading. In Fiscal Year 1997, our analyses determined the maximum areal mass loading that could meet all of the thermal goals outlined above. This determination produced the areal mass loading of 85 MTU per acre that is being used for the reference design for the viability assessment, and it confirmed that all related design goals could be met with a certain set of assumed parameters for drift diameters, drift spacing, and waste package spacings. Our analyses also showed that it is possible to place high-level radioactive waste between the waste packages containing spent nuclear fuel with a minimal impact on the design layout.

Cost estimates

The viability assessment will include an estimate of what it would cost to construct, operate, and close a repository based on preliminary design concepts. We developed a cost analysis report that presents the assumptions and format for this cost estimate; explains the estimating process, models, and techniques; and presents a life cycle cost estimate for a repository compatible with the design configuration documented for the reference design. The cost estimate covers the period beginning with submittal of a license application and reflects the cost to complete the repository and engineered barrier designs, to construct and operate the repository, and to close and decommission the repository.

Systems studies: integration and closure

Analyses of issues that involve waste acceptance, storage, and transportation functions, or that cut across the program, are conducted by our Program Management Center, as reported in Chapter Three. Analyses limited to crosscutting components of the repository system are conducted by the Yucca Mountain Site Characterization Project. Analyses completed in Fiscal Year 1997 helped us further narrow options for the reference designs that will support the viability assessment.

- *Repository seals requirements*. We examined the need for sealing the shafts, ramps, and exploratory boreholes; determined what level of performance the sealing subsystem would have to achieve to meet certain regulatory requirements; and produced recommendations for sealing the shafts, ramps, and boreholes.

- *Waste isolation*. We estimated the performance of various natural and engineered barriers in order to recommend which barriers should be considered in the license application and what is needed to substantiate that the performance of a particular barrier is licensable. We concluded that substantial performance is provided by such natural barriers as the unsaturated zone, including Calico Hills, and the saturated zone. Engineering options such as cladding, a drip shield, or low areal mass loading (thermal loading) can provide significant (an order of magnitude or greater) reduction in the total radiation dose that reaches the accessible environment. Investigations, some already planned, were recommended to validate the performance of those barriers.

- *Site-generated waste disposal options.* We conducted a detailed evaluation of options for treating and disposing of secondary wastes generated at a repository, providing a preliminary estimate of site-generated waste quantities for various waste receipt options to support the evaluation of the disposal options. Options included primarily uncanistered and canistered options for commercial spent nuclear fuel for both baseline and expanded environmental impact statement inventories. On-site and off-site disposal options for low-level radioactive, hazardous, and mixed wastes were identified and evaluated against technical, regulatory and licensing, and cost considerations. Recommendations included disposal of low-level radioactive waste at the

Nevada Test Site; minimization of the number of dual-purpose canisters requiring recycling, or development of dual-purpose canister recycling as the baseline for repository design; transportation to and disposal of hazardous waste at an approved site by a commercial, comprehensive hazardous waste disposal service; disposal of mixed waste off-site; and development and periodic updating of a site-generated waste disposal plan.

- *Waste quantity, mix, and throughput*. We identified how the parameters of waste streams influence repository surface, subsurface, and waste package design, and we defined design-basis waste streams. Three inventories of wastes were considered for acceptance at the repository: (1) baseline, or base case, to be used for the viability assessment; (2) extrapolation from the baseline to all wastes currently documented in Government databases; and (3) further extension to include other estimated waste quantities beyond the baseline. In defining design-basis waste streams, our analysis considered variations of waste inventories, use of interim storage, and a waste acceptance strategy. The impact of these variations on repository design was identified. Design levels were established considering both co-disposal and separate disposal of DOE spent nuclear fuel and high-level radioactive waste.

Evaluating Design Alternatives: *Manned or Robotic Systems?*

We currently plan to use manned locomotives to transport waste packages from surface facilities at the repository to the entrance of the emplacement drift. A remotely controlled system would emplace the waste packages in the emplacement drifts. Ventilation would be maintained until the emplacement drift was full; then the drift would be closed and ventilation turned off.

The Nuclear Waste Technical Review Board recommended that we examine whether the repository should be designed in such a way that workers could enter the drifts to perform maintenance and surveillance and to respond to off-normal situations. Because waste packages emit heat, a "manned" repository would require increasing ventilation to the level that would permit workers to enter the emplacement drifts. Because waste packages emit radiation, it would require adding shielding to waste packages to reduce workers' exposure. To examine the feasibility of these design alternatives, we conducted a trade-off analysis.

- *Ventilation of emplacement drifts*. Active ventilation of all drifts would keep temperatures at or below equipment operability thresholds. To keep the emplacement drift temperature below 50° Celsius, air flow would have to be increased—to a level 4 to 5 times greater than current design capacity. Four additional shafts would be required to move this flow. Two additional main intake drifts and two additional main exhaust drifts would be needed to move the air through the subsurface, distribute it to the emplacement drifts, and return it to the exhaust shafts. The cost of maintaining this level of ventilation for all drifts during the entire pre-closure life of the repository could be significant.

- *Shielding waste packages*. Evaluation of this option raised serious concerns. Shielding would reduce the thermal conductivity of the waste package, thereby increasing the fuel temperature and degrading the fuel cladding. It would increase the weight of the waste package, affecting handling. It would increase the cost of the waste package by $100,000- $900,000 per package, depending on the type of shielding used. Increasing the size of the package could require larger emplacement drifts, which by increasing the areal extent of the repository would increase its cost. Further, allowing personnel routine access to emplacement drifts would increase overall personnel exposures to radiation.

We believe the current design dimensions and weights of the waste packages and the emplacement mode selected for disposal are well-suited for remote handling during emplacement and that remote handling offers substantial advantages.

- *Performance confirmation*. Our assessment of this subject resulted in the development of a plan that specifies monitoring, testing, and analyses needed to (1) evaluate the accuracy and adequacy of the information used in a license application, and (2) determine that performance objectives for the period of permanent repository closure will be met.

- *Retrievability strategy*. To define a flexible strategy that can ensure that waste packages can be retrieved, we identified retrieval options and discussed the recommended retrieval process in the context of repository and waste package designs. The strategy consists of a step-by-step process for executing retrieval and a technical basis for recommended design requirements.

Performance Assessment: Key to Site Suitability and Licensing

The determination of site suitability and repository licensing will turn on the application of performance assessment: the modeling that permits scientists to use data gathered from site characterization to simulate the behavior of the repository system under a range of conditions and a variety of design options over thousands of years. In turn, feedback from performance assessment guides development of design. It also focuses scientific investigations on uncertainties associated with the most important aspects of the natural system by indicating where more data are needed to reduce uncertainties.

A total system performance assessment will be one of the four components of the viability assessment, and it will provide input for the draft environmental impact statement. If the site is recommended, another total system performance assessment will be conducted to support the license application to the NRC, using information current at that time.

In 1996, signaling the importance of total system performance assessment, the Nuclear Waste Technical Review Board recommended that we make our application of it transparent and valid, that uncertainty be treated properly, and that peer review or expert elicitation be independent. We fully agreed with this recommendation and, to attain these goals for the total system performance assessment that will support the viability assessment, we undertook three major initiatives in Fiscal Year 1997:

- A series of workshops to strengthen the technical validity of our models.

- A series of independent and objective expert elicitations to complement ongoing activities and to provide estimates of uncertainty in our modeling.

- Creation of a total system performance assessment peer review panel staffed by a multidisciplinary team of distinguished, independent scientists.

These Fiscal Year 1997 initiatives are described below.

Workshops on modeling

Nine abstraction/testing workshops provided a forum for collaboration on model development among modelers who conduct total system performance assessment, process-level modelers, and staff who perform laboratory and field measurements. Collaboration facilitates model development by ensuring that abstractions are as consistent as possible with the most comprehensive and current understanding of relevant site characteristics and processes.

Participants identified issues related to long-term performance, ranked their importance, and developed proposals for work to address key issues more explicitly in the viability assessment. Topics included unsaturated zone flow, unsaturated zone thermohydrology, near-field geochemical environment, waste package degradation, waste form and cladding degradation, engineered barrier system transport, unsaturated zone radionuclide transport, saturated zone flow and transport, biosphere, and disruptive events. The work proposals were used to guide abstraction/testing analyses that will continue into Fiscal Year 1998. These analyses provide the form of the abstracted sub-system models for input to the total system performance assessment that we will conduct for the viability assessment; they justify the use of those models; they validate them technically.

Expert elicitations

Expert elicitations on the unsaturated zone, waste package degradation, and the saturated zone complemented ongoing modeling, testing, and data collection programs while contributing to the development of total system performance assessment models. Each elicitation proceeded by (1) defining the process model inputs to total system performance assessment; (2) selecting experts to provide interpretations; (3) meeting to identify issues, data needs, methods, and interpretations; (4) compiling and disseminating data to the experts; (5) eliciting expert interpretations; (6) reviewing and finalizing the interpretations; (7) calculating and aggregating the expert interpretations; and (8) documenting the results.

The elicitations will help us develop process model descriptions that will provide technically defensible products for abstraction into total system performance assessment by properly and completely capturing uncertainties in the process models and the data that support them, in a form that is useful for total system performance assessment. Elicitations on near-field coupled effects and waste form dissolution/radionuclide mobilization are planned for Fiscal Year 1998.

The peer review panel

In January 1997, we convened a performance assessment peer review panel intended to serve two goals: (1) making our total system performance assessment transparent to technical peers, regulatory and oversight bodies, and Administration and congressional decision-makers; and (2) ensuring the traceability of decisions and assumptions that support the assessment. The panel's objective is to provide a formal, independent evaluation and critique of our development of a total system performance assessment.

The panel includes experts in the fields of risk assessment, physics and nuclear safety, chemistry and geochemistry, biosphere and health physics, material science and metallurgy, hydrology and fluid flow. It is conducting a 2-year review, in four phases: (1) orientation; (2) modeling, scenarios, and abstractions; (3) review of our draft assessment; and (4) final review. Each phase begins and concludes with an open meeting, and at the end of each phase the panel submits an interim report to OCRWM's management and operating contractor, to which it is subcontracted.

The panel is evaluating our analytical approach, including physical events and processes considered in analyses, use of appropriate and relevant data, assumptions made, abstraction of process models into total system models, application of accepted analytical methods, and treatment of uncertainty. These aspects will be evaluated within the context of the long-term performance of the repository. The panel's comments, concerns, conclusions, and recommendations will support development of the total system performance assessment for both the viability assessment and, if the site is recommended for development as a repository, for our license application.

Phase One of the panel's work began in February 1997 and concluded in June 1997. The panel's first interim report, issued in July 1997, presents the panel's understanding of our approach and of the processes and events that would affect the future performance of the repository, and initial findings based on what the panel learned during the orientation phase.

Documentation

Proper documentation addresses the validity of the models, confidence in the models, alternative interpretations, and uncertainties affecting long-term performance. The work of assembling appropriate documentation for the total system performance assessment that we will conduct for the viability assessment began in 1997 with the release of a report, *Total System Assessment - Viability Assessment Methods and Assumptions*. As an explanation of how we will implement that total system performance assessment, it served as a preliminary draft of the introductory chapters of the total system performance assessment document that we will prepare for the viability assessment. It described key components of the total system performance assessment, the general approach to producing analyses, and key model abstractions. The report was reviewed internally and externally, and several parties provided comments on the technical validity of the abstracted models, the traceability of model assumptions, and the transparency of our approach.

Background on Performance Assessment

Complex models

Total system performance assessment is an analysis in which all significant site features, events, and processes are represented in models that can be used to forecast the long-term behavior of the repository system. The assessment must capture all important components of both the engineered and natural system. It must also evaluate the uncertainty in the prediction of waste containment and isolation, as well as risks associated with uncertainty in (1) site characterization information, (2) conceptual models of subsystem performance, and (3) process models and parameters.

Data obtained from site characterization are used to create conceptual models of the features, events, and processes associated with the site, and, in some instances, alternative conceptual models. Conceptual models are then synthesized into numerical models of how natural geologic, hydrologic, geochemical, and geomechanical processes behave over time. These process models are used to enhance understanding of the controlling natural processes, such as water movement in the unsaturated zone, and to provide estimates of parameter values, such as percolation flux at the repository horizon.

Process models tend to be quite complex and involve intensive computation; typically, they do not lend themselves to inclusion in a total system performance assessment model. To provide input to that model, the process models and/or their results are abstracted: their essential components are simplified while their intrinsic form is retained. The results must reproduce or bound those of the underlying process model, which is based on data about the site.

Abstracted models for each subsystem are combined into the total system performance assessment model that is used to simulate the performance of the repository system, and to determine the effects of uncertainty, in order to identify where more information is needed. As additional site characterization data are obtained, they are used to refine the total system performance assessment models.

Simple questions

While performance assessment can be complex, the questions it addresses are simple: How adequate are our models? What do we need to do to reduce uncertainties? Where we cannot reduce uncertainties, how much do they matter and how sensitive are they to change?

Simple goals

A total system performance assessment that is *transparent* will be supported by clear and logical documentation, and it will be clear not only to technical analysts but to other informed reviewers. To be *traceable*, it will have a complete and unambiguous record of decisions and assumptions, and of models and data, and of how they were used to arrive at results. Traceability is achieved through documentation and explanation of all decisions made during the analyses. A model is considered to be *technically valid* if it provides a reasonably accurate representation of reality. The best way to demonstrate validity is through independent confirmation of models and conclusions—the approach we are taking.

Factoring Government-managed nuclear materials into our assessments

To obtain NRC authorizations to construct, operate, and close a repository that will contain waste forms from Government-managed nuclear materials, we must demonstrate how those waste forms will affect repository performance. This means that we need specific data on physical, chemical, and radiological properties. Those waste forms are more heterogeneous than commercial spent nuclear fuel; there are approximately 250 forms of DOE spent nuclear fuel.

The total system performance assessment we conduct for the viability assessment will consider all waste forms in some manner. The base case repository capacity will be assumed to be 70,000 MTHM, the statutory limit established by the Nuclear Waste Policy Act. Of that total, 90 percent by weight, or 63,000 MTHM, will be assumed to be commercial spent nuclear fuel. The remaining 10 percent will be assumed to be 7,000 MTHM equivalent of Government-managed nuclear wastes. Approximately two-thirds of the 7,000 MTHM will be high-level radioactive waste in the form of borosilicate glass logs; approximately one-third will be DOE and Naval spent nuclear fuel. While Plutonium waste forms are not explicitly treated in the base case, they--along with individual categories of DOE spent nuclear fuel--are explicitly treated in the total system performance assessment through sensitivity analyses. These analyses indicate that the contribution of plutonium waste forms to the total radiation dose to the public is bounded by the dose from an equivalent amount of commercial spent nuclear fuel and high level waste glass. The plutonium waste forms may therefor be considered to be implicitly treated in the base case.

The environmental impact statement that would accompany a site recommendation will also evaluate these waste forms for disposal in the repository. The base case for the environmental impact statement will assume the 70,000 MTHM statutory limit on repository capacity; alternatives will include assumptions of more than 70,000 MTHM.

Regulatory Issues Remain Open

Requirements of the Energy Policy Act of 1992

Repository siting and development are governed by regulations issued by the U.S. Environmental Protection Agency (EPA), the NRC, and the Department of Energy. In the 1992 Energy Policy Act, Congress directed EPA to develop radiation protection standards to apply specifically to a repository at Yucca Mountain. Congress also directed the NRC to revise its repository licensing regulations, 10 CFR 60, to reflect the new EPA standards. The Department's siting guidelines, 10 CFR 960, *General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories*, which govern selection of a repository site, must also incorporate these standards.

As Fiscal Year 1997 closed, EPA was still working to develop proposed standards, and as the NRC awaited the EPA standards, it was considering revisions to its own regulations.

Amending the Department's siting guidelines

When the Department published its siting guidelines in 1984, multiple sites were to be screened as potential candidates for repository development. In 1987, Congress directed us to characterize only the Yucca Mountain site. This change immediately rendered inapplicable several of the general siting guidelines, which were designed to facilitate comparisons of multiple sites. Another change was more gradual: since we published the guidelines in 1984, we have gained a more sophisticated understanding of what is required to assess repository performance. In our May 1996 revised *Program Plan*, we stated our intention to amend the regulatory framework for the repository to reflect (1) policy changes since enactment of the Nuclear Waste Policy Act in 1982, and (2) what had been learned from nearly 10 years of site investigations.

On December 16, 1996, we published a Notice of Proposed Rulemaking in the *Federal Register* in which we proposed amendments to the siting guidelines. The

amendments would reflect the fact that only one site is under consideration, and they would streamline the determination of site suitability for repository development to focus on overall repository system performance, rather than on independent technical considerations of individual features of the site. This reflects our belief that judgments about the Yucca Mountain site should be based on the site's ability to protect public health and safety and the environment as measured by overall system performance.

On January 23, 1997, we held a public hearing to receive comments on the proposal in Las Vegas, Nevada. We twice extended the public comment period, to a total of 151 days, ending on May 16, 1997. These extensions pushed publication of a final rule past the Fiscal Year 1997 milestone date that had been targeted in the revised *Program Plan*.

Coordination with the Nuclear Regulatory Commission

The purpose of our interactions

Under the Nuclear Waste Policy Act, if the Secretary makes a site recommendation to the President, the recommendation must include preliminary comments from the NRC to the Secretary on whether our site characterization analysis and proposed waste form appear to be sufficient to serve as the foundation for a license application. If the site recommendation is accepted by the President and Congress, the Commission must then review and issue a final decision approving or disapproving our application for a "construction authorization" within 3 years.

For our work to satisfy the Commission, and for the Commission's comments and review to be effective, we must share a common understanding of the emerging repository concept, of what the associated licensing requirements should be, and of what information will be available for the initial license application. Accordingly, OCRWM's Director presents semiannual briefings to the Commissioners, and our staffs engage in extensive and continuous informal interactions on procedural and technical issues.

In the near term, the viability assessment will provide a valuable frame of reference for our prelicensing interactions because issues essential to licensing are being addressed in it. And the Commission's views on the acceptability of our approach to licensing, as set forth in the license application plan that is a component of the viability assessment, will be important to policy-makers' decisions regarding the future direction of our program.

An expanded framework for interactions

In keeping with our conviction that the soundest measure of repository performance is the measure of total system performance, we expanded the focus of our interactions with NRC staff in Fiscal Year 1997. Beyond narrowly addressing isolated technical issues, we worked toward achieving a common understanding of issues important to overall repository performance and of the adequacy of proposed methodologies and approaches to important technical issues.

To focus its work and document progress in resolving issues with us, the Commission initiated Annual Progress Reports on its work and Issue Resolution Status Reports, which present the staff's current thinking and concerns on individual key technical issues. We reviewed the first Progress Report, issued in January 1997. We believe these reports provide insights into the NRC's approach that will help us improve the viability assessment and prepare better documents for licensing.

Within this expanded framework, our staffs discussed selected technical issues. We made progress toward resolving the issue of the potential for igneous activity, identifying points of agreement and a proposed path to resolution of remaining issues. Resolution will entail our description of how the results of our expert elicitation will be used in performance assessment and how sensitivity studies will be conducted. We understand that the Commission's staff has committed to completing, in early Fiscal Year 1998, an Issue Resolution Status Report on the probability of future igneous activity.

In June 1997, the Commission released its Issue Resolution Status Report on Future Climate Scenarios, with which we generally concur, and we resolved issues related to the use of expert elicitation. We continued to develop a risk-based criticality analysis methodology. A

topical report describing our proposed methodology for analyzing postclosure criticality will be submitted to the Commission by the end of Fiscal Year 1998. We intend to continue our dialogue on this important issue.

Following issuance of the viability assessment in 1998, we will engage in more frequent interactions with the NRC to address key technical issues and our own work products. Our ability to communicate effectively with each other and to drive issues to resolution is essential to our ability to meet our milestones.

Planned revision of NRC regulations

We continued to follow discussions regarding potential changes to the NRC's licensing requirements that will follow from new EPA radiation protection standards. NRC staff share our view about difficulties associated with evaluating subsystem performance against quantitative criteria. They have announced their intention to provide the Commission with options for possible revisions to NRC repository licensing requirements in Fiscal Year 1998.

We support the NRC's staff position, presented at the March 1997 meeting of the Advisory Committee on Nuclear Waste, that the Commission's consideration of revisions to its licensing requirements should not be on the critical path for DOE's amendment of its siting guidelines or for any assessment of the viability of the Yucca Mountain site.

The Licensing Support System evolves: exploiting new technologies

In 1991, the NRC and the Department began to plan for an electronic licensing support system that would meet the Commission's requirement for electronic access to the unprecedented volume of documents that will support a repository licensing proceeding. Requirements for this system are governed by NRC rulemaking 10 CFR 2 Subpart J.

Since plans for this system were originally formulated, information technology has advanced dramatically. In November 1997, the Commission published a draft rule proposing to move toward electronic filing of documents and the use of Web technology. We support this approach, and we are reviewing the Commission's suggested changes to its regulation and working with NRC staff to resolve comments.

We have begun reprocessing our records into image and text formats that can be accessed through the Internet, and we expect to complete this by the end of Fiscal Year 1999. We have also developed a prototype format for licensing documents that provides a link from the document to supporting information in our records system or other sources.

Protecting People and the Environment

Preparing an environmental impact statement

The Nuclear Waste Policy Act requires the Department to include an environmental impact statement as part of a recommendation to develop the Yucca Mountain site as a repository. The environmental impact statement will evaluate the effects of transporting both commercial and Government-managed nuclear wastes to the repository and of disposing of them. We began the process of developing the statement in Fiscal Year 1995 by publishing a Notice of Intent in the *Federal Register;* scoping hearings followed. The public comment period, which closed on December 5, 1995, produced approximately 1,000 comment documents. The majority addressed transportation, repository performance, legal issues, and policy issues, with transportation drawing the most concern.

Funding cuts in Fiscal Year 1996 caused us to defer work on the environmental impact statement, but in Fiscal Year 1997, work resumed with the award of a contract to support preparation of the statement and publication of a document summarizing public comments from scoping. Award of this contract, resumption of work to develop the statement, and publication of the summary of comments met several milestones in our revised *Program Plan*.

Two groups are helping us guide development of the statement and ensure coordination within the Department: an Executive Committee, which consists of Departmental Secretarial Officers, and a Management Council, which includes representatives of the Office of Environmental Management with responsibility for Government-managed nuclear materials, and representatives of the Office of the General Counsel and the Office of Environment, Safety and Health.

In developing preliminary approaches to impact assessments for the environmental impact statement, we defined assumptions that include emplacement in the repository of DOE spent nuclear fuel and high-level radioactive waste, surplus weapons-grade plutonium waste forms, and Naval spent nuclear fuel. We reviewed the scope and content of other recent environmental impact statements prepared by the Department, and surveyed existing data and identified additional data needed to prepare the statement. We also started consultations with Federal, State, and county agencies and with Native American Tribes.

In Fiscal Year 1998, we will continue these consultations, complete the development of approaches to impact assessment and perform preliminary impact analyses, write draft chapters of the environmental impact statement, and prepare information for use in appendices or reference documents. A draft environmental impact statement will be issued in Fiscal Year 1999; a final statement, in Fiscal Year 2000.

Worker safety

Our project's safety and health program requires that written safety plans and procedures be prepared before work begins. Worker training and line management accountability are critical to the program's success in ensuring worker and public safety. Active oversight is exercised through assessments, surveillances, and inspections performed by the Department and its contractors, with technical support from other Federal agencies and independent technical experts.

Excavation of the Exploratory Studies Facility main 5-mile loop and associated test alcoves, spanning 31 months of underground tunnel construction through varying ground conditions, was completed in Fiscal Year 1997 without serious injuries directly related to excavation operations.

Historically, the Yucca Mountain Site Characterization Project's annual rates of safety- and health-related incidents and illnesses have been well below those of commercial enterprises in similar industries on a national scale. They have also been below the Department's national rates. These trends continued through Fiscal Year 1997. The 5-year total recordable injury and illness rate was approximately 60 percent below the comparable industry rate; the 5-year lost-workday incidence rate was about 50 percent below. The safety and health cost index was approximately 70 percent better than the Department's complex-wide average.

Scientist Engaged in Environmental Montoring

Protecting the environment

OCRWM is committed to performing its work at the Yucca Mountain site in a manner that minimizes significant adverse environmental impacts. An environmental protection program, implemented at the start of site characterization, covers a wide range of activities and ensures that the Exploratory Studies Facility and associated structures are built, operated, and managed in a

manner that will protect, maintain, and restore environmental quality, minimize potential threats to the environment and the public, and comply with environmental regulations and Departmental policies. This program continued to function smoothly and efficiently in Fiscal Year 1997.

Data collection and monitoring. To establish and maintain a baseline against which we can assess the effects of site characterization activities and could identify the effects of repository construction and operation, we continued to monitor air quality, water quality, ecosystems, and archaeological resources. We also monitored to determine existing background levels of radiation. This baseline information will equip us to mitigate any impacts before they become significant. To date, no significant adverse environmental impacts have been detected. Data collection also supported repository design, biosphere modeling, total system performance assessment, the viability assessment, and preparation for a license application.

Surveys and reclamation. Before the start of field activities, we conducted surveys to identify threatened species, objects of cultural interest and, in certain instances, radionuclides in the soil. Reclamation plans were developed for each disturbed site to allow restoration following completion of an activity. Our habitat reclamation program developed the best techniques for reclaiming disturbed areas in the harsh desert environment.

Environmental compliance. We continued to review, analyze, and interpret Federal and State environmental laws, regulations and codes, and orders while developing and implementing strategies, plans, and procedures to satisfy environmental compliance requirements. Since the beginning of site characterization, we have obtained over 40 permits for air quality, underground injection control, drinking water, wastewater discharge, and water appropriation. In Fiscal Year 1997, we submitted to the Nevada Division of Environmental Protection and the Nevada State Engineer the quarterly and annual compliance reports required to maintain these permits.

We maintained communication with numerous Federal and State agencies on compliance matters. We maintained land access and land withdrawal agreements and several rights-of-way with the Bureau of Land Management, U.S. Air Force, National Park Service, and U.S. Forest Service to allow scientific studies at Yucca Mountain and at remote sites in Southern Nevada and California. Frequent environment, safety, and health appraisals, assessments, and surveillances ensured that project activities complied with applicable regulations, procedures, and permit conditions.

Historic preservation. Consultations and interactions with 17 Native American Tribes and organizations continued under the Programmatic Agreement between the Department and the Advisory Council on Historic Preservation. Our staff conducted visits to the Yucca Mountain site for Native American Tribes, held a project update attended by all 17 Native American Tribes and organizations, and attended a variety of national meetings.

Waste minimization and management. The environmental program continued to be an important part of day-to-day operations at the Yucca Mountain site. It included management of hazardous and solid waste disposal; waste minimization, recycling, and pollution prevention efforts; and operation of hazardous waste accumulation areas in compliance with the Resource Conservation and Recovery Act. Hazardous waste was transported off site to facilities that hold disposal permits from EPA. No hazardous, extremely hazardous, or toxic materials were released to the environment.

Other environmental efforts. Workers received environmental protection and pollution prevention training prior to working at the site. Environmental staff participated in engineering design reviews to ensure that safety and health requirements were satisfied, necessary permits were identified, and pollution prevention technology was employed. Rigorous assessments and surveillances contributed to our success in avoiding, minimizing, and mitigating any adverse environmental impacts and ensuring full regulatory compliance.

Relations with Other Parties

Interactions with Nevada State and local governments

Under the Nuclear Waste Policy Act of 1982, the State of Nevada; Nye County, in which the Yucca Mountain site is located; and nine counties contiguous to Nye

County (including Inyo County in California) were designated *affected units of government*, and they are eligible to receive Federal financial assistance to review and monitor site characterization activities. The State and Nye County also have the right to designate on-site representatives to oversee our work and to receive funding for associated "reasonable expenses." The State has never designated such a representative, but the County has, and its representative did oversee our work in Fiscal Year 1997.

For Fiscal Year 1997, Congress appropriated no funds for either the State of Nevada or the ten affected counties under this section of the Act. The State of Nevada, which remains steadfastly opposed to the Yucca Mountain Site Characterization Project, used funds it carried over from Fiscal Year 1996 to continue to operate its Nuclear Waste Project Office. Lack of funding forced many of the ten affected counties to close their nuclear waste offices, lay off staff, and curtail their review and monitoring of our work.

Nonetheless, we engaged in numerous formal and informal interactions with the affected units of government and the public. Through personal visits to the counties and a series of teleconferences, we provided many updates on project activities and issues to each of the ten county commissions. Our staff participated in a formal meeting with Lincoln County in April 1997; provided six site tours to various counties and their nuclear waste management offices; coordinated with the affected governments in monitoring teleconferences on pertinent congressional hearings on radioactive waste disposal, appropriations and transportation; and responded to more than 600 requests for information from the counties and other stakeholders. Our staff also participated in a town hall meeting held at the University of Nevada, Las Vegas, on the Yucca Mountain Site Characterization Project. And OCRWM provided 497 computers to school districts in six of the affected counties.

In September 1996, the State of Nevada sued the Department seeking funding that it claims it is owed from Fiscal Year 1996 appropriations. In its December 1996 opening brief, the State sought $3.5 million and petitioned for judicial review of the Department's decision not to provide the funding. In a January 13, 1998, decision, the U.S. Ninth Circuit Court of Appeals denied the State's petition for review, stating that the Department had fulfilled its statutory obligation under the Act: the State had sufficient funds available at the start of Fiscal Year 1996.

Under Section 116(c)(3) of the Act, the Department continued to make Payments-Equal-to-Taxes (PETT) to Nye County. These payments are intended to compensate for taxes that Nye County could have collected on site characterization and the development and operation of a repository if it were authorized to tax Federal Government activities. For Fiscal Year 1997, the payments totaled $6.4 million.

PETT funding was the subject of mediation between the Department and Benton County, Washington, that was successfully concluded in a May 1, 1997 agreement. The Department owed PETT funds to the county as a result of site characterization activities at the DOE Hanford site, which is in Benton County, during the 1980's. An initial PETT payment of $770,000 was made in 1992; under the terms of the May 1, 1997, agreement, an additional $5.25 million was paid to the County.

Outreach to the public

We continued to provide information to the general public and to support public education and participation in project-related activities. These efforts centered on informing stakeholders and the public about the status of activities at Yucca Mountain. To reach stakeholders, interested groups, and individuals in a cost-effective manner, we provided information by means of our Home Page, newsletters, fact sheets, correspondence, a toll-free telephone number, science centers, and meetings. Two videos, the Fiscal Year 1996 *Year in Review* and a video documenting the "daylighting" of the tunnel boring machine, depict various aspects of our program for general audiences.

We participated in 201 speaking engagements, reaching over 13,500 stakeholders through the Yucca Mountain Speakers' Bureau, and we conducted 182 tours of Yucca Mountain, briefing nearly 3,000 visitors on our progress in characterizing the site.
A major opportunity for formal public involvement was the public hearing held in January 1997 on the Department's proposal to amend its repository siting guidelines.

We reached more than 20,000 Nevada students in grades kindergarten through 12, as well as more than 300 Nevada teachers, through such activities as workshops on energy, geology, and environmental studies; science "discovery days"; classroom presentations; field trips; and participation in the JASON project, a nationwide, interactive science exploration program.

Meeting with professional and academic organizations

As in years past, our staff met with many professional associations, including the Association of Engineering Geologists, the U.S. Army Corps of Engineers Geotechnical Conference, the American Chemical Society, the Geological Society of America, the American Society for Metals, the American Geophysical Union, and the Institute of Nuclear Materials Management. We also met with students and professors from university science and public policy departments, such as the Mackay School of Mines at the University of Nevada at Reno, and many of them visited the Yucca Mountain site. All of these meetings helped build wider understanding of OCRWM's program within the public policy, scientific, and technical communities.

International Collaboration

OCRWM's international waste management activities involve formal collaborations with other countries and international organizations to exchange information and develop consensus on common issues. During Fiscal Year 1997, we participated in bilateral agreements with Canada, Sweden, Switzerland, France, Japan, and Spain to support information exchanges. Interactions continued with the International Atomic Energy Agency, and we continued to play an active role in the Nuclear Energy Agency, which represents approximately 30 countries.

The focus of our ongoing international cooperative work is interpretation of site characterization data and performance assessment. This work involves continuing participation in two programs of the Nuclear Energy Agency: the Site Evaluation and Design of Experiments Group and the Performance Assessment Advisory Group. These groups work cooperatively to improve the state of the art in geosphere transport and two-phase flow characterization and modeling, and in performance assessment and modeling. OCRWM's participation in these activities strengthens the capabilities and defensibility of our models of natural processes that operate at the Yucca Mountain site.

Interest in the Yucca Mountain Site Characterization Project remained high among other nations that are developing their own nuclear waste management programs. In Fiscal Year 1997, visitors from Sweden, South Korea, Taiwan, Canada, China, and Hungary visited the Yucca Mountain site and met with project scientists to learn about our work.