

Chapter One

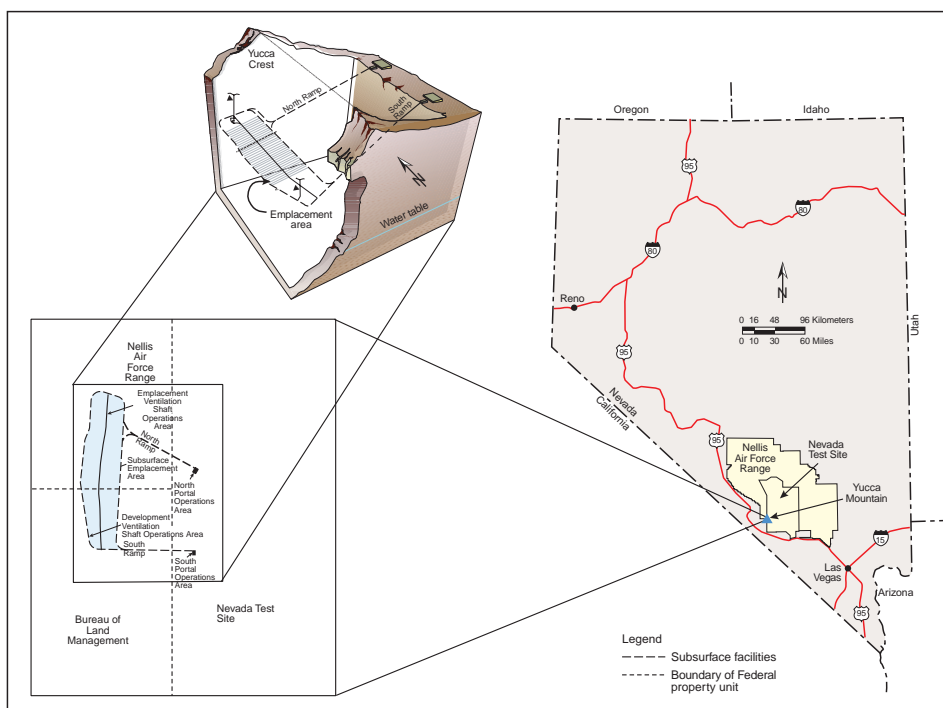
Yucca Mountain Site Characterization Project

Background on the Project

Located 100 miles northwest of Las Vegas, Nevada, on remote and semiarid Federal land, Yucca Mountain has for many years been the subject of studies to support a determination of whether it should be developed as a repository for spent nuclear fuel and high-level radioactive waste. If a repository is developed there, OCRWM will accept waste from the sites where it is stored, transport it to Yucca Mountain, and emplace it in the repository. A plan for closing the repository will be developed, but future generations would decide when to permanently close it.

The site characterization studies of Yucca Mountain have generated a huge volume of information. Ensuring the integrity of the information, evaluating it, and presenting it in forms that other parties can use is a significant task, as is interacting with other parties. By the time site characterization ends, approximately \$4 billion and 18 years of effort will have been invested in studies of Yucca Mountain and design of a repository tailored to its features.

At the conclusion of site characterization, the Secretary of Energy will draw upon the information we have produced and on other sources to determine whether this information is necessary and sufficient to recommend to the President that a repository be developed at the site. If the Secretary does recommend the site for development, and if the President recommends the site to Congress, then the State of Nevada will have an opportunity to disapprove the designation. If Nevada disapproves the designation, Congress must act to designate the site for development. If the site is designated, DOE must submit a license application to NRC for authorization to construct a repository. Subsequent license amendments would authorize operation and eventual closure.



Location of Yucca Mountain candidate repository site

In Fiscal Year 1999, the Project focused on preparing

the documentation needed to support the Secretary’s determination on site recommendation. This chapter reports on preparations for this determination, which entailed updating the repository safety strategy that guides site characterization; refining and further documenting performance assessment models, reducing scientific uncertainties, and enhancing repository design; issuing a draft environmental impact statement; and updating the regulatory framework for evaluating site suitability. It also reports on our interactions with external oversight bodies and other parties, continuing efforts to protect workers and the environment, and significant project management functions.

The \$282.4 million allocated to the Project for Fiscal Year 1999 work was distributed as shown below.

Core science:	\$74.8M
Design and engineering:	78.4
Site suitability, licensing, and performance assessment:	53.1
National Environmental Policy Act compliance:	2.0
Operations and construction:	34.2
Project management:	28.2
External oversight and payments-equal-to-taxes:	11.7

The funding profile for the Project has shifted as the work of site characterization has moved toward completion.

Preparing for the Determination on Site Recommendation

The work we did in Fiscal Year 1999 to support the Secretary’s determination whether to recommend the site for development of a geologic repository built directly on the *Viability Assessment of a Repository at Yucca Mountain*, which was released on December 18, 1998. It presented the first comprehensive description of a potential repository at

the Yucca Mountain site and of its expected performance in minimizing potential radioactive dose levels over thousands of years. Summing up 15 years of site investigations, it concluded that the work required to determine the suitability of the site for a repository should proceed. It identified key technical areas in which uncertainties about repository system performance should be reduced, and it described the additional work required to reduce them and to eventually submit a license application to NRC. The viability assessment thus narrowed the focus of site characterization studies. In addition, information from semiannual site characterization progress reports to NRC and the Governor and legislature of the State of Nevada, required under the Act, are also being utilized to support the consideration of site recommendation.

Section 114 of the Act requires the Secretary to hold public hearings near the site prior to a determination, and it states that in making a recommendation,

...the Secretary shall make available to the public, and submit to the President, a comprehensive statement of the basis of such recommendation....

Section 114 specifies that the comprehensive statement, which we term a Site Recommendation Report, is to include the following:

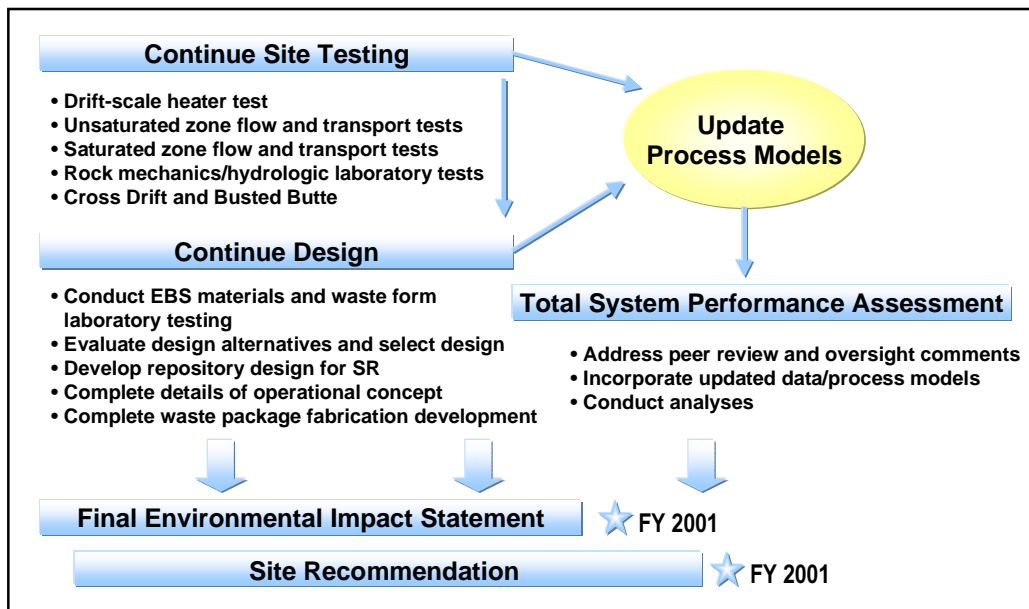
- a description of the proposed repository, including preliminary engineering specifications for the facility;
- a description of the waste form or packaging proposed for use at such repository, and an explanation of the relationship between such waste form or packaging and the geologic medium of such site;
- a discussion of data, obtained in site characterization activities, relating to the safety of such site;
- a final environmental impact statement prepared for the Yucca Mountain site;
- preliminary comments of NRC concerning the extent to which the site characterization analysis and the waste form proposal for such site seem sufficient for inclusion in an

application submitted by the Secretary for licensing of the site as a repository;

- the views and comments of the Governor and legislature of the State of Nevada, together with the response of the Secretary to such views;
- such other information as the Secretary considers appropriate; and
- any impact report submitted by the State of Nevada.

In Fiscal Year 2001, we plan to release a Site Recommendation Consideration Report to inform the public of a potential Secretarial site recommendation and to solicit the views and comments of the public. Public hearings on the potential recommendation will also be held. Designed to provide information on the first three of the Section 114 requirements, above, it

Preparing this report, planning for and conducting the hearings, and managing the collection of other information required by the statute is a major undertaking. To ensure that all information is properly assembled and that all requirements of the Nuclear Waste Policy Act are satisfied, we continued, in Fiscal Year 1999, to closely analyze the Act and applicable regulations, and prepared a detailed work plan to govern preparations for the Secretarial determination. The bulk of this work has entailed the formal integration of what has been learned from the principal components of our site characterization program. Those components consist of scientific studies of the Yucca Mountain site, design of the engineered barriers that would isolate radionuclides and retard their migration to the accessible environment, and a total system performance assessment that synthesizes the results of scientific investigations and engineering into a forecast of repository system performance.



Work leading to site recommendation

will consist of two volumes summarizing the results of site characterization: one will describe a repository system for Yucca Mountain; the second will present a preliminary evaluation of site suitability conducted under the Department's guidelines.

The Repository Safety Strategy

Site characterization studies have been designed for two closely related purposes: (1) to produce information that the Department needs to evaluate site suitability, and (2) to satisfy NRC regulations for

licensing a repository. Central to both is a requirement that the Department demonstrate that a repository at Yucca Mountain would perform safely for thousands of years after it is closed. The postclosure safety case presented in the Site Recommendation Consideration Report will include the following:

- predictions, based on total system performance assessment, of how the repository system would perform after it is closed;
- consideration of how potentially disruptive processes and events could affect repository system performance;
- descriptions of various approaches to demonstrating defense-in-depth, including reliance on multiple barriers to mitigate uncertainties in characterizing the performance of the natural and engineered barriers of the repository system; and
- understanding gained from relevant natural analogues to the Yucca Mountain site.

Our approach to making the postclosure safety case is shaped by a repository safety strategy. It rests on assumptions about four key attributes of a repository system at Yucca Mountain that we formulated by analyzing information about the site and the likely performance of engineered barriers in that setting:

- Limited water would contact the waste packages.
- Waste packages would last a long time.
- Radionuclides would be released from the waste packages slowly.
- Radionuclide concentrations would be reduced during transport through engineered and natural barriers.

These assumptions have remained essentially unchanged since we issued a Site Characterization Plan in 1988, but the details of the repository safety strategy have evolved as our work has progressed. In Fiscal Year 1999, we further updated the strategy to

reflect information presented in the viability assessment. The revised strategy identifies what we now believe to be the factors most important to evaluating repository system performance and what information we need to develop in order to complete the safety case.

Together, the assumptions and the factors important to demonstrating that the assumptions are reasonable constitute a conceptual framework for assessing overall repository system performance. In Fiscal Year 1999, this framework helped scientists and engineers focus data collection, analyses, and modeling on factors important to demonstrating that the performance of natural barriers, the waste package, and other engineered barriers will satisfy regulatory standards for protecting the public. The insights of peer reviewers and oversight bodies also shaped our research, which principally addressed the following:

- volumes and rates of, and mechanisms for, water infiltration and seepage into the repository;
- pathways and mechanisms for transportation of radionuclides through the saturated zone;
- the nature of interactions between engineered barriers and natural processes, including the effects of heat generated by waste;
- how candidate waste package materials would perform over long periods of time, under varying conditions;
- how enhanced repository design concepts could improve safety; and
- how process models could more accurately represent site conditions and waste package performance.

To reduce uncertainties about key factors, we conducted field and laboratory tests, analyzed data, assessed alternative designs, and conducted performance assessments to determine which uncertainties matter most and which are most sensitive to new information that could be obtained from further field and laboratory testing.

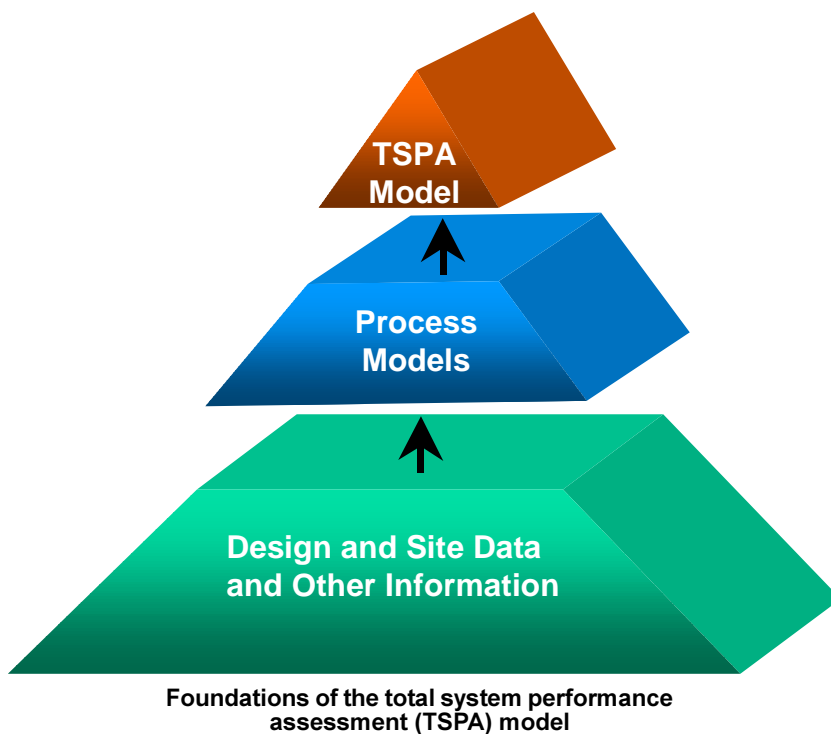
Performance Assessment

The results of performance assessment analyses are a major component of the repository safety case that will be presented in the Site Recommendation Consideration Report, the Site Recommendation and in a license application.

Working within the framework of the repository safety strategy, performance assessment integrates information from site investigations, laboratory studies, expert judgment, and repository design into a set of numerical models that represent the total repository system. The total system model is used to simulate how a repository at the site might perform under a range of conditions over thousands of years after it was closed. We use it to evaluate repository system performance against proposed regulatory criteria, determine the contribution from each engineered barrier to performance, and identify uncertainties in our understanding of performance. We then determine how to reduce the uncertainties by evaluating how sensitive they are to new information from scientific studies or how we might compensate for uncertainties by enhancing design.

The result is a forecast of the radiation dose a person might receive from radioactive waste emplaced within Yucca Mountain. That dose must not exceed regulatory standards if the repository is to be demonstrated to be safe.

In Fiscal Year 1999, we refined the models used in the viability assessment to reflect new information from site investigations and laboratory studies, advances in modeling physical processes at the site, and an enhanced repository design; the scientific and engineering work reflected in these refinements is described below. Model refinement will be completed in Fiscal Year 2000 and an iteration of total system performance assessment will be conducted for the Site Recommendation Consideration Report.



Documenting the foundation for determining site suitability

If a determination on site suitability is to be accepted and understood, our performance assessment models must be defensible and traceable. To ensure that they are, we began, in Fiscal Year 1999, to develop two sets of reports that describe in detail the bases for our total system performance assessment, from compilation and analysis of data to model development. This work was informed by expert elicitations conducted in support of the viability assessment.

Process Model Reports describe the technical basis for each sub-model of the models for each of nine major physical processes that would govern performance of the repository system. The reports present the technical information needed to ensure that models are defensible and that data and references can be traced to their sources. Their subjects are the integrated site model, the flow of water and transport of radionuclides in the unsaturated zone, flow and transport in the saturated zone, the near-field environment around waste packages, waste package degradation, waste form degradation, degradation of

the engineered barrier system and flow and transport through it, the biosphere, and potentially disruptive events.

Supporting Analysis and Model Reports cover analysis of site and laboratory data, incorporation of these data into detailed process-level models, and abstraction of process-level modeling results into sub-models for inclusion into the overall system-level model.

The complexity of performance assessment modeling that will support determinations on site recommendation can be illustrated with the prediction of how quickly waste packages would corrode. To accomplish this we must quantify the amount of water that would contact the waste packages. This requires estimating how much water could enter the site over a specified period of time, examining how water would flow through the porous media of the site to enter waste emplacement drifts and how temperature gradients due to heat generated by spent nuclear fuel would affect the behavior of water, the geochemistry of the near-field environment, and the engineered barriers. All this information must be represented in numerical models, and the sources of the information and analyses that support the models must be documented, along with the software code used to run the models.

Peer Review

A peer review panel had been convened in 1997 to provide an independent evaluation of the total system performance assessment conducted for the viability assessment and to help us make our work transparent to technical peers and regulatory and oversight bodies. This panel included experts in all fields related to repository performance. Panel members evaluated 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. They also reviewed supporting documentation, including process-level models; attended technical meetings; and reviewed documentation for the total system performance assessment as it was being prepared. Their insights

contributed to development in Fiscal Year 1998 of the total system performance assessment used in the viability assessment.

In February 1999, the panel delivered its final report to us, and we factored its findings, comments, concerns, and recommendations into our work plans for the remainder of Fiscal Year 1999 and for Fiscal Year 2000.

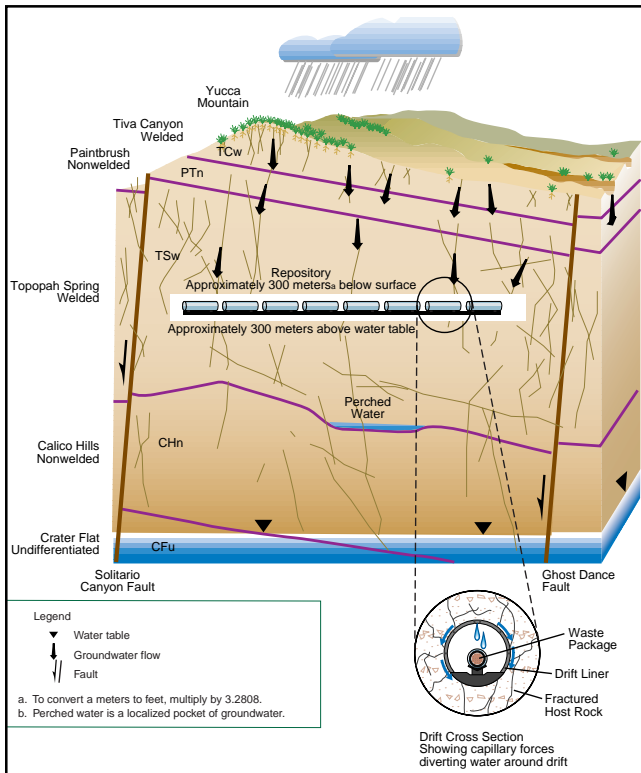
Core Science

Guided by the repository safety strategy, Fiscal Year 1999 site investigations focused on obtaining data we can use to reduce key scientific uncertainties about factors important to repository performance and to refine predictive models of how the engineered and natural barriers of a repository system would perform. By better defining the range of variability in natural processes at the site, testing and monitoring enabled us to make our performance assessment models more accurate. By confirming predictions of conditions we would encounter in site investigations, testing and monitoring helped us validate models. Investigations above and below ground yielded data on geologic, geochemical, geomechanical, and hydrologic features and processes and the coupled mechanical and chemical effects of heat on rock. Some of this work was completed in Fiscal Year 1999; some has continued.

We augmented site investigations with laboratory testing, and we continued to use the results of independent peer reviews to verify the appropriateness of the methods and approaches used in site investigations. We also used data from site investigations to define the physical conditions against which the results of future testing and monitoring would be evaluated under the Performance Confirmation Program as required by NRC regulation.

Test facilities

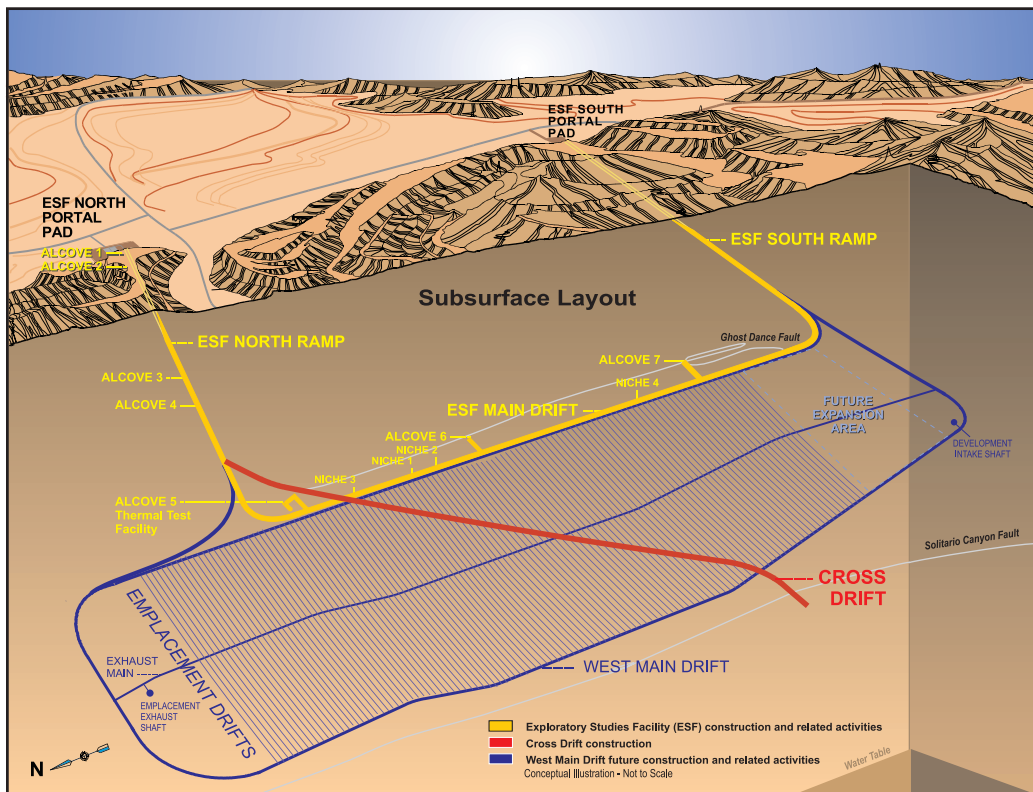
In Fiscal Year 1999, site investigations were carried out within test facilities we have constructed at the Yucca Mountain site. The illustrations on the following page show natural features of the site and test facilities in operation and under construction.



The facilities' hub is an underground Exploratory Studies Facility, the main loop of which is 7.6 meters (25 feet) in diameter and nearly 8 kilometers (5 miles) long. Transecting the main loop is a tunnel, 2.8 kilometers (1.67 miles) long and 5 meters (16.5 feet) in diameter, called the cross-drift, that gives us direct access to the central and western portions of the proposed repository block and to the geologic strata where approximately two-thirds of the waste emplacement tunnels would lie.

A test facility at Busted Butte offers direct access to the Calico Hills formation, rock similar to that beneath the repository. By studying pathways, quantities, and rates at which water travels through this rock, scientists learned more about the potential for radionuclide transport from the repository down 300 meters (1,000 feet) to the water table. We started excavating two one-cubic-meter blocks of rock that will be sent to a laboratory for testing and analysis to determine the radionuclide transport properties in the Calico Hills formation.

Natural features of proposed repository block



Proposed repository subsurface layout and cross drift



Test facility at Busted Butte



Constructing a monitoring station at Crater Flat

Geologic and geochemical data were obtained from more than 350 boreholes drilled from within underground facilities, more than 450 boreholes drilled from the surface, and over 200 pits and trenches. Monitoring wells yielded hydrologic data and Global Positioning System stations measured small movements in the earth's surface.

To ensure the integrity of rock, soil, and water samples, staff at the Project's Sample Management Facility continued to document each sample's chain of custody and to maintain the data in a computerized database. We installed a fiber-optic data network in the Exploratory Studies Facility and the cross-drift—environments in which the presence of many electrical devices creates severe electromagnetic interference. This network ensures the reliability of data transmission, and by instantaneously transmitting data to network servers that back it up, it greatly increases data security and integrity.



Drilling activities near Yucca Mountain

We completed excavation of the cross-drift on October 13, 1998, and we finished installing utilities (ventilation, power, water, compressed air, and lighting) to the end of the tunnel. We installed bulkheads across the tunnel and initiated moisture monitoring under the high infiltration region beneath the crest of Yucca Mountain and in the Solitario Canyon fault zone. The cross-drift bulkhead studies will provide data on moisture and seepage in the Topopah Springs Lower Lithophysal and Lower Nonlithophysal Units and in the Solitario Canyon fault zone.

In Fiscal Year 1999, we started excavating Alcove 8 (the “crossover alcove”) within the cross-drift, and we configured the conveyor and ventilation systems to initiate excavation of Niche 5. Construction of both the alcove and niche should be complete in Fiscal Year 2000. Alcove 8 will provide data on flow and seepage between the cross-drift and Niche 3, which is located within the repository host rock in the Exploratory Studies Facility, and it will provide field-scale data on flow, seepage, and matrix diffusion within the unsaturated zone over a scale of tens of meters. Niche 5 will provide data on air permeability and seepage in the Topopah Springs Lower Lithophysal Unit and data on seepage and the variability of hydrologic parameters in the proposed repository host rock.

Drilling of a surface borehole, SD-6, started in Fiscal Year 1998; in Fiscal Year 1999, it was completed to a depth of 856 meters (2,808 feet). It provides data on the stratigraphy and hydrology of the western portion of the proposed repository block. We also completed drilling a surface

borehole to obtain preliminary geotechnical information needed for design of a repository surface facility, the Waste Handling Building.

Understanding the unsaturated zone

The unsaturated zone is the area of rock above the water table. The repository would be located in that zone, about 300 meters (1000 feet) beneath the surface and about 300 meters (1000 feet) above the water table. In Fiscal Year 1999, a peer review panel completed its review of the approach and methodologies we are using to model radionuclide transport through the unsaturated zone beneath the repository horizon. The panel observed that currently there is no preferred alternative model to ours, but it recommended several ways to technically enhance and validate our model. We are evaluating its recommendations and developing a plan to implement them.

Performance assessments for the viability assessment identified seepage of water into emplacement tunnels and onto waste packages as a possible cause of waste package degradation and eventual release of radionuclides. Determining under what conditions, in what quantities, and at what rates water would seep into drifts and onto waste packages is the subject of continuing study.

The Nuclear Waste Technical Review Board has identified seepage as a critical issue and stated its support for our plans to continue experiments and modeling to investigate it. In September 1999, the peer



Drilling in Alcove 8

review panel we had convened to review the potential for seepage into drifts submitted its report. We are evaluating its recommendations and will develop a plan that will enable us to implement them in Fiscal Year 2000.

In Fiscal Year 1999, major experiments involved measuring seepage at several locations and under two general types of conditions: ambient, in which we measure the amount of natural infiltration of water into test areas, and forced, in which we introduce water into test areas and measure the resulting infiltration. To test deep percolation and seepage through the highly fractured rocks of the Ghost Dance Fault, we constructed Alcove 7 within the Exploratory Studies Facility. The alcove is 200 meters (660 feet) long and approximately 220 meters (726 feet) below the surface. Bulkheads within the alcove isolate faulted and non-faulted sections of rock to limit the drying effects of the ventilation system. Despite this isolation, no seepage has yet been observed in this alcove.

Forced-flow experiments enabled us to investigate how underground openings similar to waste emplacement tunnels alter the groundwater flow field, possibly diverting water into surrounding rock. Using several niches at repository depth in the Topopah Springs tuffs and one alcove closer to the surface of the site, in the Tiva Canyon tuffs, these experiments examined the distribution and amount of seepage that might occur in waste emplacement drifts.

Infiltration tests in the Topopah Springs tuffs involved introducing water above a niche and observing the resulting seepage in the opening. Tests were completed in Niche 2; they are under way in Niche 3. Unlike most of the Exploratory Studies Facility, which is dry due to ventilation, Niche 3 is isolated from ventilation and has high humidity that simulates post-closure repository conditions. Air permeability tests using boreholes were conducted before and after excavation in Niche 4, in a highly fractured region along the main drift of the Exploratory Studies Facility.

Tests in Niche 2 examined seepage into a welded tuff with low fracture density, investigating the flow of air and water through the rock both before and after construction in order to determine the effects of construction on permeability. Data indicated an

increase in air permeability after construction due to changes in rock stress and fracture aperture induced by excavation.

The theory of flow near underground openings predicts that surface tension between water and air near the drift wall can inhibit seepage into the drift. Infiltration tests investigate the influence of these capillary effects in diverting flow away from the excavation. Termed "a capillary barrier," this diversion may play an important role in limiting the contact of water with waste packages. Numerical models used in performance assessment help us design experiments that provide data that can be used to test the concepts and the numerical implementation of the models. The results of testing in Niche 2 suggested the existence of a capillary barrier. When the numerical model is calibrated to the field tests, it can support predictions of drift seepage under a variety of potential repository conditions. The numerical simulations indicated the likelihood that the capillary barrier could prevent seepage up to groundwater flux rates of 200 millimeters per year, far in excess of the tens of millimeters per year currently estimated to pass vertically through the repository horizon.

Alcove 1 is located near the north portal of the Exploratory Studies Facility, closer to the surface of the site than the other test facilities, in the Tiva Canyon welded tuffs. Experiments in that alcove simulated the flow that might result from higher rainfalls in a future climate that is wetter and cooler than the present. The results provided insight into near-surface infiltration processes and the processes and volumes of seepage into underground openings. Scientists divided the roof of the alcove into separate areas of about 0.1-square meter. At the site surface above the alcove, they applied water to a 91-square meter area, while observing seepage in a 44.2-square meter collection area within the alcove. It took 58 days for water to travel from the surface to the collection system, but once flow had been established, changes in the rate at which water was applied at the surface produced corresponding changes in seepage into the alcove within a few days.

Detection of chlorine-36 in the Exploratory Study Facility had raised speculation that it resulted from

nuclear testing conducted in the 1950s in the Pacific Proving Grounds and, to a lesser extent, at the nearby Nevada Test Site. This, in turn, raised questions about groundwater pathways and travel times. Our study of this matter had indicated the presence of fast pathways for groundwater migration from the surface of the site to the repository horizon. In Fiscal Year 1998, the independent peer review we had commissioned to review our study was completed. The panel generally agreed with our approach, methodology, and interpretation of data. It recommended enhanced geologic sampling strategies for isotopic measurements and closer integration with other groundwater-tracer data and flow modeling.

In Fiscal Year 1999, as recommended by the panel, we implemented a sampling and analysis program using boreholes drilled from within the Exploratory Studies Facility and cross-drift. Sampling was completed and analyses are currently under way; results will support the Site Recommendation Consideration Report. On the panel's recommendation, we also started drilling subsurface boreholes from within the Exploratory Studies Facility. Data will be used to determine the distribution of "bomb-pulse" chlorine-36 and to increase our understanding of the potential for preferential pathways for radionuclide transport. This in turn will help us calibrate flow and transport models of the unsaturated zone. At two bomb-pulse locations within the Exploratory Studies Facility, the Sundance Fault and Drillhole Wash Fault zones, we completed chlorine-36 and chlorine mass balance studies.

Understanding the saturated zone

Beneath the unsaturated zone lies the saturated zone, the region in which rock pores and fractures are completely saturated with groundwater. Because radionuclides could migrate through this zone to the accessible environment, we need to understand its characteristics. The Nuclear Waste Technical Review Board has stated its belief that we need to better understand it and supports our plans to further characterize it.

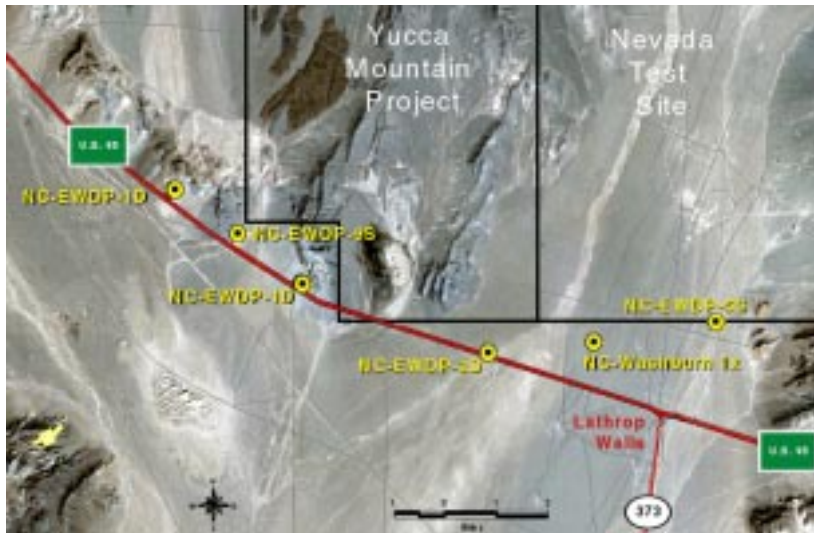
In Fiscal Year 1999, efforts focused on Phase 1 of the Nye County Early Warning Drilling Program. Nye County, the county within which the Yucca Mountain

site is located, is designing a series of boreholes for use as part of an early warning system that could be part of performance confirmation monitoring if a repository is developed at the site. Nye County is conducting its drilling program in cooperation with, and with funding from, OCRWM.



Nye County Early Warning Drilling Program

During the fiscal year, Nye County concluded Phase 1 of its drilling program, completing eight monitoring wells that reach the saturated zone from six drilling sites near Amargosa Valley. Project scientists accompanied Nye County scientists during sample collection and hydrologic testing. Information from rock and groundwater samples collected during and after drilling has been integrated into our conceptual model of the saturated zone. Stratigraphic data from the drilling program and information about the flow and transport properties of the alluvium and valley fill aquifer have been incorporated into our site-scale model. Information on the County's drilling program can be found on the County's Web site: www.nyecounty.com



Locations of completed Nye County drill holes

To obtain data on local and regional water table elevations and fluctuations through time, we continued to take measurements at the network of 22 water monitoring boreholes drilled by our Project. We used the data to assess the seasonal transient effect of precipitation and evaporation, as well as the effects of local and regional water use and potential impacts on repository operations. These ongoing measurements helped us determine the range of variability in the natural environment, and we used the information to calibrate the regional and site-scale groundwater models.



Monitoring water table fluctuations at a borehole

Fiscal Year 1999 brought completion of the C-Wells tracer-testing program, which yielded critical data on the hydraulic properties of the volcanic aquifer, an estimate of flow and transport properties of materials in the aquifer, and laboratory confirmation of the transport properties of those materials from core samples. Test results indicate the range of variability in the flow properties of the hydrogeologic and hydrostratigraphic units within the aquifer and the influence of fracture density on flow rates. These data will be used to test and improve models of radionuclide transport parameters and travel times.

Understanding the effects of heat on repository system performance

A subject of long-term studies is how heat generated by radioactive decay of waste would alter the surrounding environment. Heat-induced changes in rock mineralogy, mechanical properties, rock and water chemistry, and site hydrology would affect the rate at which waste packages degrade and radionuclides are released and the mechanisms and pathways by which radionuclides could be transported. One speculation is that as heat caused water to vaporize, salts would precipitate. Salts could then be redissolved by moisture that condenses and returns, making the moisture a corrosive fluid capable of degrading waste packages and accelerating their eventual failure.

To closely examine these phenomena, DOE's Lawrence Berkeley, Lawrence Livermore, Sandia, and Los Alamos National Laboratories are conducting three tests that use electric heaters to simulate heat generated by waste. Very different in scale, all three tests contribute data on the effects of thermally driven hydrologic, chemical, and mechanical processes in rock. Scientists use these data to develop models of how the engineered and natural barriers of a repository system at Yucca Mountain would respond to heat.

- **The large block test at Fran Ridge** generated data on how heat affects the movement of moisture through rock, the mechanical and chemical responses of rock to heat, the geochemistry of refluxing water, and microbial activity. It involved heating a large

could affect coupled thermo-hydraulic processes that in turn would affect flow and transport in the rocks. This information is needed for models of the near-field environment, the waste package, and the engineered barrier system.



Large block heater test

block cut out of exposed repository host rock. Heaters operated from February 1997 until March 1998; cool-down was completed in September 1998, as scheduled. Post-heating data collection and most of the analyses were completed in Fiscal Year 1999. Results indicate that under the test conditions, groundwater in the block flowed by gravity below the heated region and could transport radionuclides, with fractures acting as the dominant flow conduit. Results also indicate the potential presence of “heat-pipes” – geologic structures that could bring water into contact with waste-packages even in a repository in which the temperature reaches the boiling point. These findings provide vital information on how heat emitted by waste

- **The single heater test**, a large-scale underground test, began in August 1996. It employed one heater approximately 5 meters long to heat a 21-cubic-meter (27-cubic yard) volume of rock over a period of 10 months. Instrumentation included over 300 thermometers that continuously fed data through cables to a computer that recorded approximately 700 channels of information. The results provided initial information on the thermo-mechanical-hydrologic-chemical behavior of the rocks at the potential repository horizon. The test was completed as scheduled in the spring of 1998. During Fiscal Year 1999, the results were analyzed. They are being incorporated into Process Model Reports for the Site Recommendation Consideration Report.

- **The drift scale test** is the largest such test in the world. In a simulation of an actual waste emplacement drift, an underground alcove approximately 48 meters (156 feet) long is being heated for 4 years by electric heaters placed in the walls and floor. The heaters placed in the drift are similar in dimensions and materials to actual waste canisters. The test is designed to heat an estimated 15,000 cubic meters (about 19,600 cubic yards) of rock to a temperature above 100 degrees Centigrade.

Remotely controlled video and infrared cameras monitor this test, and from remote locations scientists can continuously modify system parameters and retrieve data by telephone. Automation permits more accessible, consistent, and reproducible testing, and it allows scientists to spend their time analyzing data instead of physically collecting them. This automated system is supplemented by a limited amount of manual sampling.

The heaters were turned on early in Fiscal Year 1998, ahead of schedule. After 4 years, they will be turned off, and cool-down will be monitored for another 4 years. Data collection continued during Fiscal Year 1999.

Significant results, to date, from the single heater test and the drift scale test include identification of conduction as the dominant heat transfer mechanism and the preliminary indication that rock porewater mobilized by the heat tends to drain by gravity, via fractures in the rock mass, to below the heated region rather than staying perched above it.

Laboratory and field testing

Another important line of inquiry is determining the pathways, mechanisms, and rates at which radionuclides could be transported from the near-field environment that surrounds waste packages if the packages are breached. Studies examine how phenomena such as the solubility limits of specific radionuclides, dispersion and diffusion during

transport, and dilution could minimize resultant dose levels.

Fiscal Year 1999 laboratory testing focused on strengthening our understanding of transport of radionuclides through the unsaturated and saturated zones, by gathering more data on how radionuclides could sorb to rock along transport pathways. The tests involved measurements of sorption coefficients for host rock and the potential for transport of radionuclides by colloids, very fine particles suspended in groundwater. Tests were conducted by scientists at DOE's Sandia, Lawrence Livermore, and Lawrence Berkeley National Laboratories, and the U.S. Geological Survey.

For the unsaturated zone, tests using tracer elements as surrogate radionuclides to measure sorption were conducted in the Busted Butte facility, which provides direct access to rock identical to that below the potential repository host rock. The measurements were made to demonstrate that sorption data collected in laboratory experiments are applicable to site-scale transport modeling. Test results were verified by controlled laboratory measurements on Busted Butte samples using actual radionuclides. They show that sorption of neptunium, a critical radionuclide contributing to radiation doses, is an order of magnitude higher than previously thought.



Preparing for a test using tracer elements to study rock properties

In other tests at Busted Butte, we investigated colloidal migration using polystyrene microsphere, a surrogate colloid. Results show that there was virtually no migration of the colloid through the Calico Hills Formation. Laboratory tests on reversibility of radionuclide sorption by colloids are nearing completion. The colloidal materials tested include iron oxides and clay minerals. The preliminary results indicate that clay mineral-type colloids may show irreversible sorption for plutonium and americium, making them potential transporters of highly insoluble radionuclides.

For the saturated zone, sorption measurements were made in the alluvium samples collected in cooperation with the Nye County drilling program. Data analyses will be completed and the results will be included in the saturated-zone process model used for the Site Recommendation Consideration Report.

To increase confidence in our measurements of transport parameters, we continued to evaluate data about radionuclides in the groundwater of other DOE sites and to use them to verify our transport model. Those sites are the Nevada Test Site, the Hanford site in Washington, and the Idaho National Engineering and Environmental Laboratory. Observations from these analogue sites will be included in the transport models being prepared for the Site Recommendation Consideration Report.

Building a regional groundwater model

We continued work on a major 5-year project to develop a comprehensive regional hydrologic model, sharing databases with the Nevada Test Site; the U.S. Geological Survey; the Bureau of Indian Affairs; Nye, Inyo, Lincoln, and Clark Counties; the National Park Service; the Air Force; and the Nevada State Engineer's Office. The model will incorporate the best features of two independently produced models. The Test Site's model was developed to study existing contamination; it focuses on transport phenomena on a micro scale. Our model is a tool for simulating and evaluating effects of climate change on the regional water table.

Fiscal Year 1999 activities included fieldwork to gather new data and refinement of the regional hydrologic framework model. This effort will yield a more comprehensive model more closely calibrated to observations of actual conditions at the site, both steady-state and transient. The steady-state model will be completed by the end of Fiscal Year 2000; the transient model by the end of Fiscal Year 2002.

Building a three-dimensional model of the site

Data from site investigations were interpreted and extrapolated to build and refine a three-dimensional, integrated model of site hydrogeology—in effect, a picture of what we know about rock layers, faults, rock properties such as porosity and hydraulic conductivity, and mineralogy, including the presence of zeolites (minerals to which some radionuclides can sorb and which, therefore, have the potential to retard radionuclide migration). This integrated site model represents geologic features within an area of 65 square miles and a volume of 185 cubic miles, to a depth of 13,000 feet, as interpreted from data taken from boreholes drilled from the surface of the site to depths of up to 6,000 feet, data from drifts, and other sources such as gravity and magnetic data. The site model was the basis of the site description presented in the viability assessment, and it is the framework for hydrologic studies and repository design investigations.

In Fiscal Year 1999, important validation of our understanding of the site came with confirmation of our predictions of the geologic features that we would encounter in excavating the cross-drift and drilling two boreholes from the surface of the site to a depth of over 2,500 feet. The data input, methodologies, and assumptions used to construct the latest version of the three-dimensional model were documented in a report that was completed in early Fiscal Year 2000. Later revisions of the report will incorporate any new data acquired at the site.

Developing the Performance Confirmation Program

Under NRC regulation, if a repository is developed at Yucca Mountain, DOE must conduct a testing

program to confirm the performance of the natural and engineered barriers that are the basis for the safety case presented in the license application. NRC regulations also require that a repository be kept open for at least 50 years after the start of waste emplacement; our plans would not preclude its being kept open for at least 125 years, and, with a reasonable expectation of appropriate maintenance, for up to 300 years. The repository would be monitored by remote-sensing devices hooked up to computers.

The performance confirmation program we are developing entails monitoring, testing, and analyses. In Fiscal Year 1999, we continued to define the current physical conditions against which repository performance would be compared and to define tests and related activities necessary to monitor performance. Factors to be monitored would include air temperature and relative humidity; the presence and types of radioactive gases; soil and rock temperature, stress, deformation, and displacement; and moisture, vapor, and fluid temperature and conditions in the zone altered by heat generated by radioactive decay of waste.

Design and Engineering

The documentation supporting the Secretary's determination on site recommendation will rest in part on a substantial body of design work. In Fiscal Year 1999, we adopted a set of enhanced design features for a repository that will support the Secretary's determination, and we began to further develop them. Another task in direct support of the Secretary's determination was documentation of major repository subsystems important to safety. Laboratory testing and engineering studies augmented design work.

Design continued to be closely integrated with performance assessment modeling and core science data collection and testing. Integration with performance assessment ensured that models reflected the latest designs and that designers could consider where design enhancements might reduce uncertainties in predictions of repository system performance. Integration with core science ensured

that designs were supported by data on the natural features of the site, including structural, thermal, and hydrologic rock properties, and information on potential climate and seismic conditions.

Enhancing repository design

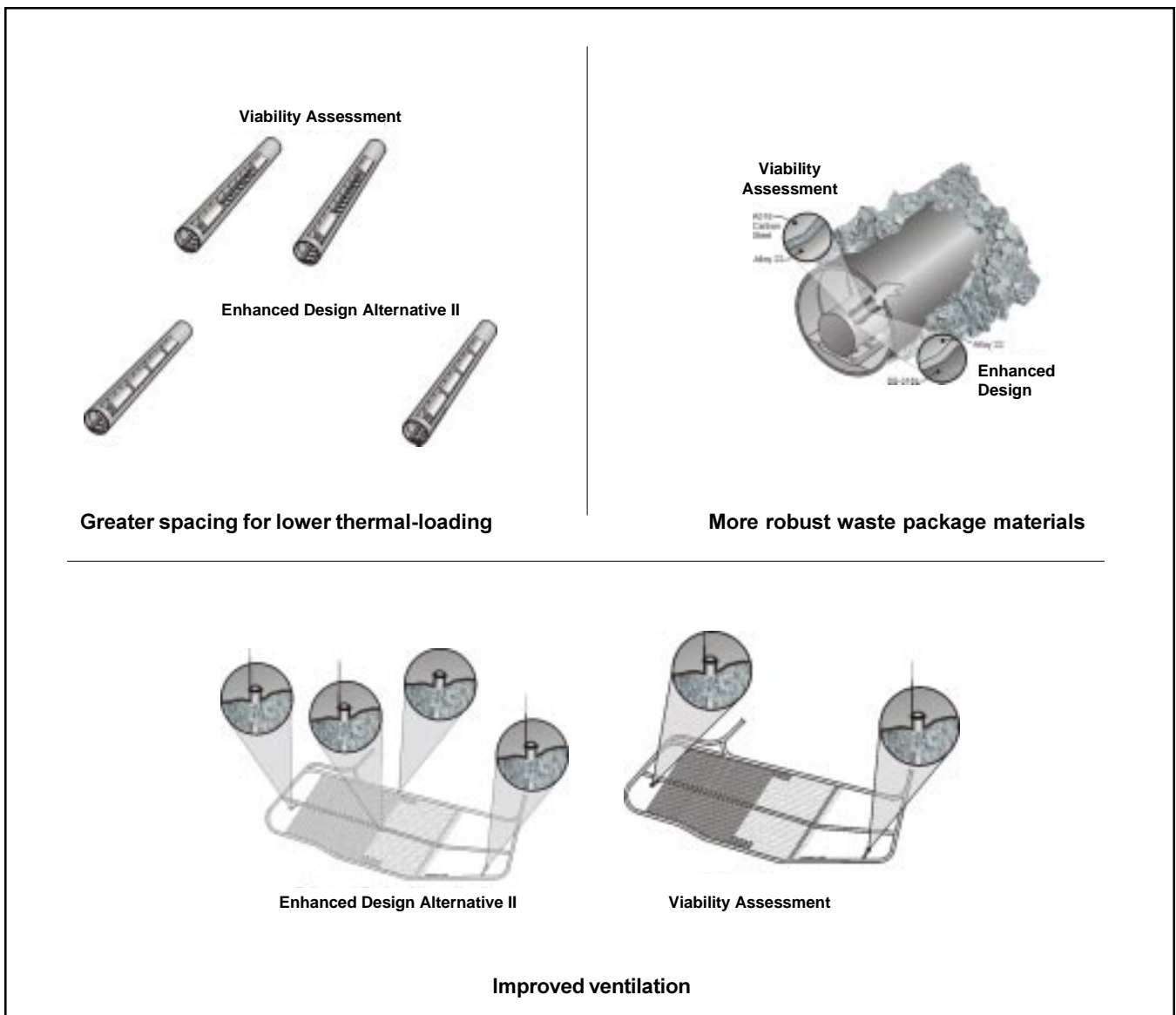
Wastes to be emplaced in a repository contain various types of radionuclides. Our studies indicate that the natural features of the site could contain most of them for long periods of time, but a small fraction appears to be mobile. Under some conditions they could be transported from the repository by water. The engineered barriers we are designing, together with the natural barriers of the site, would limit the amount of water that contacts radionuclides.

Our designs have been evolving over many years. To reduce uncertainties about repository system performance and to respond to Nuclear Waste Technical Review Board concerns about the reference design used in the viability assessment, we began, in July 1998, a study of alternative design concepts. We formulated and evaluated a wide range of design alternatives against a set of criteria: long-term public safety, worker safety, generational equity, cost, and how long-term repository performance could be demonstrated in a licensing proceeding. We sought to maintain flexibility in design, so that as new information—from confirmatory testing, scientific and technological advances, operational and cost considerations, the demands of the licensing process, evolution in national policy, or some other source—arose, further enhancements could be made, even after the repository has been licensed. We also sought to maintain the flexibility that would permit future generations to decide when to close the repository by weighing technical and institutional considerations at that time.

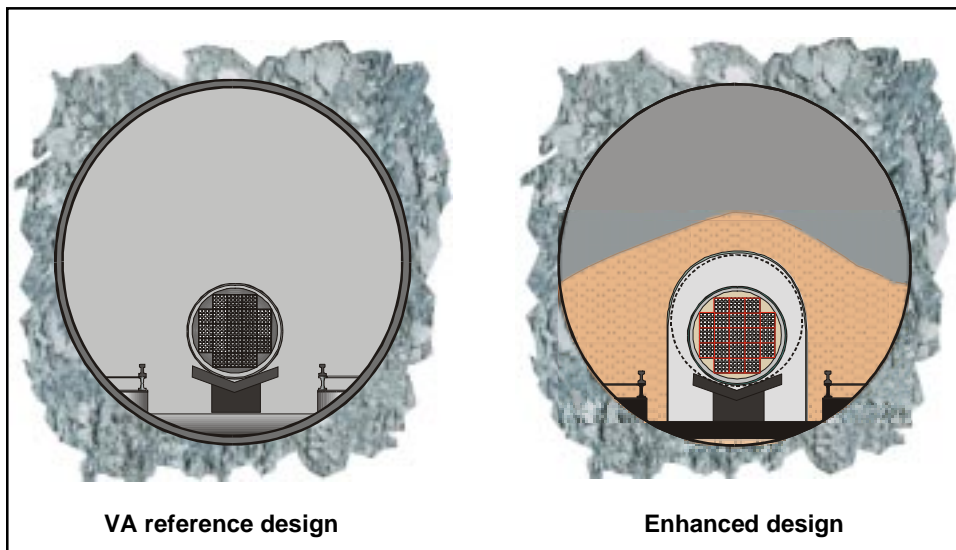
The study was completed in April 1999. We used the results and subsequent analyses, along with policy considerations, to select the next-generation design concept. It will be the basis for the total system performance assessment that will support determinations concerning site recommendation and serve as the starting point for the design concept presented in a license application. Some of the most

important features of the enhanced design concept concern thermal-loading: how hot the repository would be as a consequence of heat generated by spent nuclear fuel and where that heat would be distributed. We recognized that temperature may have a profound effect on the cumulative uncertainty in predictions of long-term repository system performance, and that this uncertainty, in turn, may affect confidence in a determination on site suitability. We, therefore, chose what can be characterized as a lower thermal-loading

design that uses more intensive thermal management techniques than the viability assessment reference design. These techniques include thermal blending of fuel assemblies, closer spacing of the waste packages, wider spacing of the emplacement drifts, and preclosure ventilation. Waste package design was enhanced, and a drip shield that would protect waste packages from water and possible rockfalls was added to the engineered barrier system.



The enhanced design makes several improvements over the VA design



An enhanced design could include drip shields and backfill

is fabricated: a waste package made with Alloy-22, a highly corrosion resistant nickel-chromium-molybdenum alloy, on the outside and a reinforcement cylinder of 316-series stainless steel on the inside would offer greater resistance to corrosion and more confidence in predicting corrosion rates.

The drip shield would be made from 15- to 20-millimeter-thick titanium that would cover the top and full sides of the waste package. Before settling on the new

Besides contributing to design decisions, the study advanced our understanding of the relative importance of the many factors involved in repository design. Details on design enhancements are presented in the sidebar below and in the September 10, 1999, letter from OCRWM’s Acting Director to the Nuclear Waste Technical Review Board, which is posted on the Board’s Web site at: www.nwtrb.gov

Another design change made in Fiscal Year 1999 was adoption of solar power as the source of electricity for the subsurface ventilation system. This change would not enhance repository system performance, but it would be environmentally beneficial.

Designing waste packages and the drip shield

Waste packages will make a major contribution to the repository system’s ability to isolate waste and retard the migration of radionuclides. While several waste package designs will ultimately be needed to accommodate waste forms of different dimensions and the necessary criticality safety measures, the primary features—the thickness of the inner and outer barrier walls—are the same for all designs.

Our new waste package design boosts expected performance by changing the materials from which it

waste package design and drip shield, we performed rudimentary shielding, thermal, structural, and criticality analyses to justify their selection. More in-depth analyses will be performed to support the Site Recommendation Consideration Report. We also analyzed candidate backfill materials to determine their ability to divert water, their structural properties, and their impacts on heat transfer.

We submitted the *Disposal Criticality Analysis Methodology Topical Report* to NRC in Fiscal Year 1999. It explains how we will evaluate waste packages to demonstrate criticality safety during the post-closure period. The NRC accepted the report for technical review, and we held two technical exchanges with NRC staff to further the review. We are expecting a Safety Evaluation Report from NRC that will identify those aspects of the Topical Report that NRC accepts.

We have also completed two additional studies related to criticality. One supplements the Topical Report by presenting the results of additional benchmarking exercises to validate models used to predict the composition of commercial spent nuclear fuel; another presents a process for evaluating criticality safety during the pre-closure period.

Features of the Enhanced Repository Design

Features of the enhanced repository design concept include the following:

- **Thermal management techniques would lower temperatures within the repository block.**
 - **Waste packages would be cooler.** The maximum heat output of each waste package would be lower because adding extra processing space in the Waste Handling Building would allow us to do more “thermal blending.” This involves mixing hotter assemblies with cooler ones to average out temperature differences between waste packages and greatly reduce the variation from the average to the hottest package.
 - **Areal mass loading would be lower.** Within emplacement drifts, waste packages would be placed much closer together end-to-end, generating more heat in any given drift, but drifts would be spaced farther apart (81 meters compared to 28). The combined effect would reduce the number of metric tons uranium (MTU) per acre and thus the amount of heat generated per acre: areal mass loading would fall on average from 85 MTU/acre to around 60 MTU/acre.
 - **Potential for hot spots would be reduced.** Placing hotter waste packages next to cooler ones would allow the heat in the hotter packages to be transferred to the cooler ones. This would “smooth out” temperature differences between them and reduce the potential for local hot spots.
- **Water shedding away from waste packages would be facilitated.** In the previous design, boiling areas could have coalesced, and increased uncertainty where drainage would occur. In the enhanced design, wider spacing between drifts would prevent boiling areas from overlapping, and it would allow a significant portion of the pillar rock temperature to remain below boiling, allowing condensation and drainage between the emplacement drifts and away from waste packages.
- **Waste packages would last longer.** The double-shelled packages would contain two barriers: an outer barrier that would be very corrosion-resistant and an inner barrier of stainless steel that would provide structural protection. The first package breach due to corrosion is predicted to occur well beyond 10,000 years.
- **Drip shields would extend waste package lifetimes.** Highly corrosion-resistant drip shields placed over the waste packages would divert any water that might eventually seep into repository openings. By protecting the waste packages for long periods of time, the drip shields would extend the life of the corrosion-resistant outer shell of the waste package.
- **Preclosure ventilation would be increased significantly.** This could remove some water from within the repository rock mass and help maintain lower peak temperatures both before and after the repository is closed.
- **Ground support would minimize the use of concrete.** More extensive use of steel within emplacement drifts could reduce uncertainties associated with the potential effects of concrete on radionuclide transport.

Laboratory testing to support design

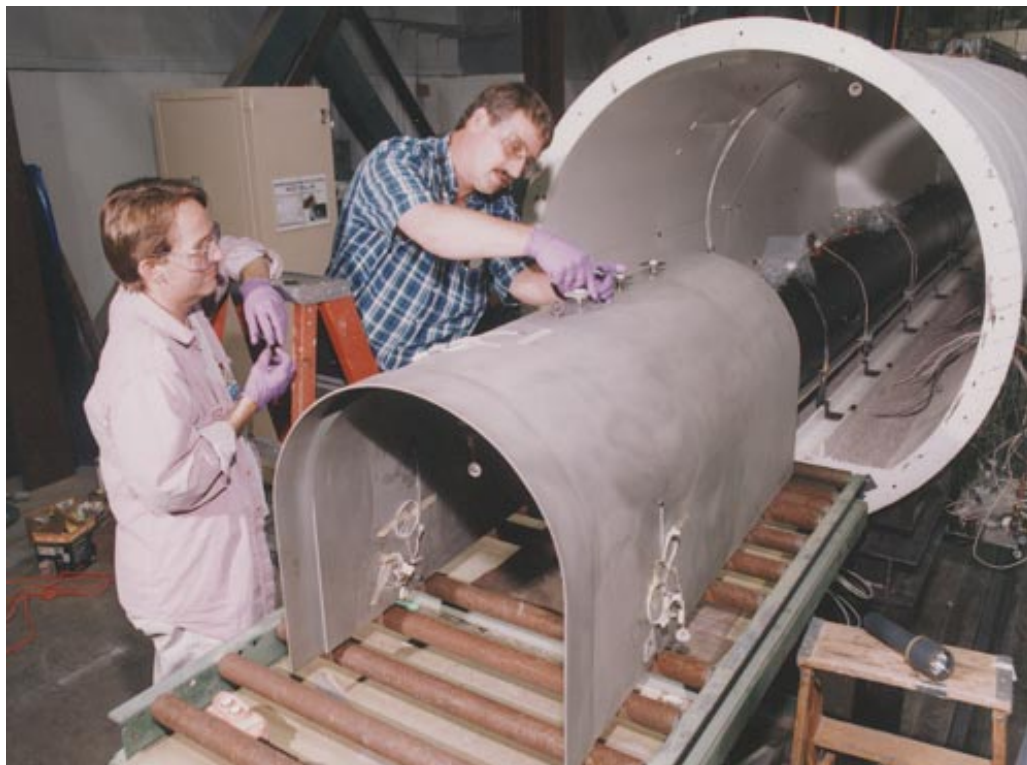
Laboratory testing contributed data that will support determinations on site recommendation. In Fiscal Year 1999, to examine how some key features of the enhanced repository design would affect the release of radionuclides, we established the Atlas engineered barrier system test facility in Las Vegas. A quarter-scale simulation of a waste emplacement tunnel, it is designed to test the drip shield and a Richard's Barrier, which is designed to function as a barrier to liquid flow. Tests determine how effectively each would prevent seepage onto waste packages. Backfill materials to enhance repository performance and mechanical stability were also tested. Test results will be included in the Process Model Report on the engineered barrier system that supports the Site Recommendation Consideration Report.

The Richard's Barrier tests were partly completed on a group of material types, and preliminary results indicate that some of the materials can act as effective barriers to water flow in a repository environment. Further experiments were put on hold in order to conduct high-priority tests on the drip shield and backfill materials.

Experimental testing programs investigate the long-term corrosion and degradation mechanisms that would affect waste package materials. The data obtained enable modelers to predict package lifetime under repository conditions. The programs were started in 1996 and will be conducted for at least 5 years, with possible extension up to 10 years.

In Fiscal Year 1999, tests were modified to reflect changes in the waste package design. Corrosion testing on carbon steel ended because carbon steel is

no longer a candidate waste package material. Long-term tests continued on corrosion-resistant materials. Short-term tests continued on galvanic protection, crevice corrosion, stress corrosion cracking, aging and phase stability, and microbiologically influenced corrosion. Results have shown that, for materials selected, general and localized corrosion should not limit the life of the waste package. Stress corrosion cracking and aging and phase stability studies have been identified as warranting further investigation, and those investigations are being conducted.



Preparation of a pilot-scale drip shield



Waste package testing

Waste package material testing and modeling were performed at Lawrence Livermore National Laboratory, the General Electric Corporate Research and Development Center, the Babcock and Wilcox Research Laboratories, and Atomic Energy of Canada, Ltd.

Waste forms themselves (spent nuclear fuel assemblies and high-level waste canisters) are part of the engineered barrier system, as they are designed to contain radionuclides. To determine the degradation behavior of waste form material, long-term tests on commercial spent nuclear fuel and vitrified high-level waste continued. Investigations of the condition of commercial spent nuclear fuel cladding after storage, and its degradation thereafter, are ongoing, and new models are being developed. Studies of colloids and fuel oxidation as well as investigations of in-package chemistry and radionuclide solubility continued.

Long-term tests of waste forms began around 14 years ago and are planned to continue until 2020. In addition to generating data that can be used to characterize mechanisms for waste form degradation, they yield data for establishing parameters for empirical models. Results have reduced uncertainties

in models of waste form degradation, and continued confirmation testing will help reduce uncertainties about the physical processes most important to repository performance.

Waste form testing and modeling are being performed at DOE's Pacific Northwest, Lawrence Livermore, Argonne, Idaho National Engineering and Environmental, Sandia, and Los Alamos National Laboratories.

Engineering studies

Because OCRWM would accept plutonium waste forms in a repository, we must understand how they would affect repository operations and performance. In Fiscal Year 1999, we completed the *Plutonium Can-in-Canister Waste Form Preclosure Radiological Safety Report*. Based on the reference design described in the viability assessment, it examines design basis events (hypothetical scenarios developed to account for all plausible events within a system) that could occur above and below ground at the repository before it is permanently closed, and it analyzes them to calculate off-site doses to the public that could result. The analysis is used to establish specifications for acceptance of these waste forms, and it helps us determine how to design the repository to reduce any potential impacts.

During the fiscal year, to focus and prioritize engineering work on those elements of the repository that are most important to safety, we revised the safety classification analysis of systems, structures, and components to reflect a risk-based approach.

Developing canister specifications for DOE spent nuclear fuel

OCRWM would accept for disposal spent nuclear fuel managed by the Department; this fuel consists of over

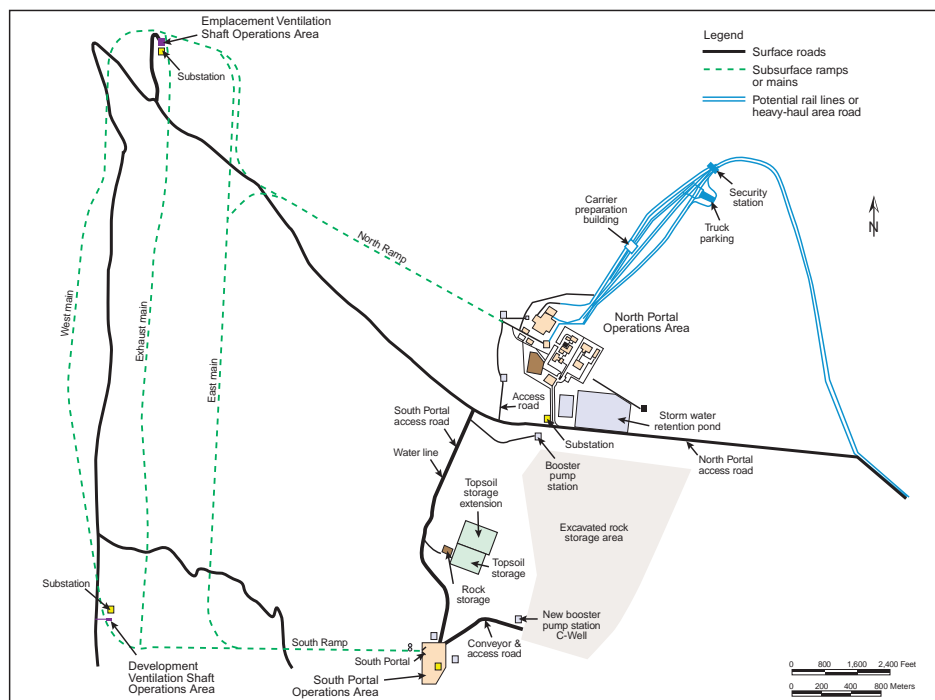
250 types, the characteristics of which vary widely. To support a determination of whether to recommend the site, as well as a potential license application and eventual waste acceptance, we continued to work closely with the Office of Environmental Management’s National Spent Nuclear Fuel Program to develop specifications for a suite of standardized canisters that will accommodate all types of DOE spent nuclear fuel. That office, not OCRWM, funds this work.

In Fiscal Year 1999, our joint efforts focused on analysis of proposed canister designs loaded with representative fuel types. The analyses chiefly examined criticality, design basis events, and total system performance assessment of the canisters, both alone and within the context of the total repository system. We established external dimensions for the canisters and are now demonstrating viable designs for configuring representative DOE fuel types within canisters. We will perform more analyses in Fiscal Year 2000 to cover more representative fuel types and to determine more accurately the performance of canisters loaded with spent nuclear fuel.

Designing repository surface facilities

Occupying about 100 acres, repository surface facilities would initially support the excavation, construction, loading, and ventilation of repository tunnels. Eventually, they would receive spent nuclear fuel and high-level radioactive waste and prepare it for disposal. Shipping casks containing waste would be received from rail or truck carriers at the Carrier Preparation Building. Waste would be removed and loaded into waste packages in the Waste Handling

Building, where waste packages would be welded shut. Low-level waste generated during waste handling operations would be prepared for disposal. Vehicles used to transport sealed waste packages to a holding area and then to emplacement drifts would be serviced at the Transporter Maintenance Building. Major surface facilities would also include a Waste Treatment Building, site utilities, and other support facilities, such as warehouses, maintenance shops, and administrative facilities.



Repository surface and subsurface facilities plan

During Fiscal Year 1999, work on design of surface facilities supported the major study of enhanced design alternatives, through evaluation of various design features and alternatives. We also evaluated a configuration for the Waste Handling Building for the following purposes:

- Determining how much surface storage capacity would be needed to allow for selection and thermal blending of commercial spent nuclear fuel assemblies.

- Allowing for a larger storage area so that enough spent nuclear fuel assemblies would be on hand at any one time to permit the blending of hot and cool fuel needed to maintain waste package heat specifications.
- Evaluating two concepts for handling bare commercial spent nuclear fuel: pools of water versus dry hot cells. The configuration of the Waste Handling Building will depend on whether wet handling or dry handling operations are selected.
- Evaluating concepts for constructing the Waste Handling Building. A single building for all operations could be constructed at one time, or individual operating modules could be constructed in phases to spread costs out over time.

Documenting design to support the determination on site recommendation

The repository design consists of design packages for each of the major repository subsystems, such as the materials handling system, the carrier/cask transport system, and the disposal container handling system. An important part of the documentation that will support the Site Recommendation Consideration Report will be the system description documents that we are developing for major repository subsystems related to safety. The documents are part of the technical baseline, and they specify requirements and criteria for a specific repository subsystem and describe the resulting design.

To support eventual receipt of a license to construct a repository, system description documents would be developed for all major repository systems. The entire suite of documents would constitute life-cycle records of repository development and would be retained as permanent records.

Draft Environmental Impact Statement

The Nuclear Waste Policy Act requires that an environmental impact statement (EIS) be included in

the “comprehensive statement” that would accompany a site recommendation by the Secretary. The EIS must be developed in accordance with the National Environmental Policy Act (NEPA) of 1969.

On July 31, 1999, we completed the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. It provides background, data, and analyses that can help decision-makers and the public understand the potential environmental impacts that could result from the actions the Department may propose: constructing, operating and monitoring, and eventually closing a repository at Yucca Mountain. It also examines the impacts of transporting waste from around the country to the repository.

The draft EIS also analyzes the consequences of continued storage of spent nuclear fuel and high-level radioactive waste at current sites under a No Action Alternative that provides a basis for comparison to the proposed action. The document states that the Department’s preferred alternative is to proceed with the proposed action, as its analyses did not identify any potential environmental impacts that would be a basis for not proceeding with the proposed action. The draft was released in the form of hard copy and a CD-ROM. It is posted on our Web site at:

www.rw.doe.gov

In the course of developing the draft EIS, we consulted interested organizations to discuss their concerns and to obtain information pertinent to the EIS. These include interactions with agencies that would have oversight or approval authority over some aspect of the repository, including the Nuclear Regulatory Commission, Environmental Protection Agency, Bureau of Land Management and the U.S. Air Force.

The public comment period extended from August 13, 1999, through February 28, 2000. We held public hearings as part of this process, scheduling ten in Nevada and eleven in cities around the United States.

The National Environmental Policy Act Process

The National Environmental Policy Act (NEPA) of 1969 specifies steps that Federal agencies must follow when developing an EIS. The process encourages early public involvement in defining the scope and content of the statement, and it requires Federal agencies to provide opportunities for public comments on the draft EIS.

The Nuclear Waste Policy Act specifies how NEPA requirements must be applied to a proposed repository at Yucca Mountain, and it states that the Secretary need not consider the need for a repository, alternatives to geologic disposal, or any sites other than Yucca Mountain. Nonetheless, we evaluated a No-Action Alternative in order to provide a basis for comparison with the proposed action: development of a repository.

During the fiscal year, we held periodic meetings to interact with and brief stakeholders on issues related to the draft EIS. Among the groups we met with are the Consolidated Group of Tribes and Organizations and affected units of local governments. Because the latter are particularly interested in transportation issues, we briefed their representatives on the details of how we analyzed transportation issues in the draft EIS and conducted a training course on the transportation models used in the draft EIS.

Public comments and responses will be documented in a Comment Response Document that will be part of the final EIS, scheduled for release in Fiscal Year 2001.

The Regulatory Framework for Repository Development

The Nuclear Waste Policy Act of 1982 assigned to the NRC responsibility for licensing geologic repositories, and it required that a regulatory framework govern certain statutory determinations about repository development. It directed DOE to issue general guidelines for selecting repository sites for site characterization, EPA to set generic radiological protection standards for repositories, and NRC to establish rules it would apply in licensing repositories.

The 1987 Nuclear Waste Policy Amendments Act limited characterization of candidate repository sites to

Yucca Mountain. The Energy Policy Act of 1992 directed EPA to develop site-specific radiation standards for a repository at Yucca Mountain, and it directed NRC to revise its repository licensing regulations to be consistent with the EPA standards. Between February and November 1999, EPA, NRC, and DOE released proposed regulations that reflect site-specific criteria to regulate a repository at Yucca Mountain.

The proposed regulations reflect a shift away from a generic evaluation of site suitability to a site-specific evaluation that relies on an overall systems approach to repository performance. The specific standards established by EPA and implemented by NRC in its licensing regulations will be central to evaluating the technical suitability of Yucca Mountain as a repository site.

Department of Energy siting guidelines

When the Department issued repository siting guidelines at 10 CFR 960 in 1984, multiple sites were under consideration for a repository. The 1987 Nuclear Waste Policy Amendments Act identified Yucca Mountain as the sole site to be studied. In December 1996, DOE published a Notice of Proposed Rulemaking, proposing to modify its guidelines by adding a site-specific subpart for evaluating the suitability of the Yucca Mountain site. The proposed approach would not contain requirements relative to how individual subsystems of the repository would perform. Rather, it would require an assessment of how the total repository system would perform and a comparison of that predicted performance with the regulatory limits on permissible radiation doses for members of the public living near Yucca Mountain.

After evaluating the comments we received, and in light of EPA's proposed radiation dose standard and NRC's proposed licensing regulations, both described below, we revised our 1996 proposal and published it

for public comment, in the *Federal Register* as 10 CFR 963 on November 30, 1999. We held four public hearings over a two-day period as part of this process, both in Nevada in the vicinity of the site. The comment period closed on February 28, 2000.

Environmental Protection Agency radiation protection standards

EPA's site-specific radiation standards for a repository at Yucca Mountain would establish limits on annual radiation doses to individual members of the public from repository releases before and after the repository was permanently closed. The Energy Policy Act of 1992 requires that the standards be based on and consistent with findings and recommendations of the National Academy of Sciences. The Academy issued its report in 1995. On August 27, 1999, EPA published in the *Federal Register* a proposed rule, 40 CFR 197, for site-specific health and safety standards.

In keeping with interagency cooperation, several Federal agencies provided technical information to EPA before EPA issued its proposed rule. The White House Office of Science and Technology Policy and the Office of Management and Budget coordinated interactions among EPA, DOE, NRC, the Navy, and the Department of the Interior.

EPA's rule is divided into two subparts:

- Subpart A sets standards for the period of repository operations and monitoring before the facility is closed. It proposes that DOE must ensure that no member of the public receive more than an annual dose of 15 millirems (mrem/year) from management and storage of radioactive materials inside the repository and outside the repository but within the Yucca Mountain site.
- Subpart B proposes three separate standards after the repository is permanently closed: (1) the individual protection standard limits doses to 15 mrem/yr. from all pathways of radionuclide travel to an individual at 20 km from the repository, assuming no human intrusion into the repository occurs; (2) the

groundwater protection standard sets a separate limit of 4 mrem/year for contamination of groundwater, and EPA presented four options for a compliance distance for public comment; (3) the human intrusion standard sets a 15 mrem/year limit to an individual at 20 km from an assumed intrusion into the repository from above. DOE must demonstrate, using the performance assessment techniques described below, that there is a reasonable expectation that the standards will not be exceeded for 10,000 years following disposal.

In response to EPA's request for public comments on its proposed rule, we submitted comments on November 26, 1999. EPA plans to finalize the rule in Fiscal Year 2000. The proposed radiation standards for Yucca Mountain are posted on EPA's Web site at: www.epa.gov/radiation/yucca/rule.htm

Nuclear Regulatory Commission licensing regulation

On February 22, 1999, NRC proposed to establish a new licensing regulation at 10 CFR Part 63 that would apply only to a repository at Yucca Mountain. The proposed rule removes the previous performance requirements for each subsystem of a repository and the technical criteria for siting and engineering, leaving overall performance objectives for preclosure and postclosure phases of the repository as the measures of acceptable repository performance. It requires that DOE demonstrate compliance with overall performance objectives through an integrated safety analysis of preclosure operations and a performance assessment for long-term postclosure performance.

NRC held five public meetings in Nevada between March and June 1999 to discuss and get feedback on the proposed regulation. We presented preliminary comments on the proposed rule during the first two public meetings. The Department's final comments endorsed the Commission's strategy of using risk-informed, performance-based overall performance objectives and removing both subsystem performance objectives and siting and engineering criteria.

The public comment period on the proposed rule extended through June 30, 1999. Commission staff are reviewing more than 1,000 comments. They plan to present the proposed final rule to the Commission for approval in calendar year 2000.

After EPA issues final standards for Yucca Mountain, NRC is expected to amend its rule to be consistent with them. NRC's proposed regulation for Yucca Mountain is posted at: http://ruleforum.llnl.gov/cgi-bin/rulemake?source=YM_PRULE

Protecting Workers, the Public, and the Environment

Fostering a nuclear safety culture

Field work can be inherently dangerous. Safety is our top priority, and we have an outstanding safety record in the field. Our Standards/Requirements Identification Document identifies safety requirements and contains detailed instructions that describe the work to be performed, potential hazardous conditions, and steps and tools that can mitigate hazards. Instructions cover construction, maintenance, operations, and testing. In Fiscal Year 1999, we completed the development of over 500 detailed work instructions.

We also worked to foster the safety culture that the NRC demands of potential licensees for nuclear facilities. This includes strict compliance with safety requirements, attention to detail, personal accountability, continuous self-assessment and improvement, avoidance of complacency, and regular and critical reviews of work. We built accountability into operating procedures and maintained it through annual employee appraisals; a policy calling for application of progressively severe disciplinary measures, if necessary; and a "Time Out For Safety" policy that empowers employees to take immediate action whenever they have a safety concern.

Other management tools included additional training on environment, safety, and health requirements; analysis to determine root causes of incidents that compromise safety; and clear definitions of roles and responsibilities for all actions. Performance indicators and self-assessments supported a process of continuous improvement. The incidence of reporting

and evaluating "near-miss" events rose, while harm to employees remained well below the Department average.

One instance of our commitment to safety was a safety stand-down imposed in June 1999 as a result of a near-miss involving surface drilling into a high-voltage electrical cable. The incident produced no injuries, but was significant enough in potential harm that management decided to terminate all activities in that work area until the root causes of the incident were fully understood and preventive practices were put in place.

Our progress in complying with the Secretary's requirement that all DOE sites have an integrated safety management system in place and verified by September 30, 2000, is reported in Chapter 3.

Environmental protection

OCRWM developed an environmental program before site characterization began in order to ensure compliance with all required Federal and State environmental requirements and DOE orders. We perform our work at the Yucca Mountain site in a manner that minimizes adverse environmental impacts. In support of construction and testing both above and below ground, in Fiscal Year 1999 our environmental staff continued to meet responsibilities that ranged from training new employees on their environmental obligations to reclaiming approximately 4.33 hectares (11.0 acres) of disturbed areas where site characterization activities had been completed.

Obtaining and maintaining required environmental permits is important to site characterization activities. Without them, work cannot proceed. Among the many activities subject to permits are air quality, underground injection of water for drilling, drinking water, waste water discharge, water appropriation, and land management. In Fiscal Year 1999, we maintained compliance with over forty environmental permits, plans, and procedures, and our environmental program continued to evolve to address new regulatory requirements. As required to maintain these permits, we continued to submit quarterly and annual compliance reports to the Nevada Division of

Environmental Protection and other regulatory agencies. We also maintained land access and land withdrawal agreements and rights-of-way reservations with the Bureau of Land Management, U.S. Air Force, National Park Service, and U.S. Forest Service. These agreements facilitate seismic studies at Yucca Mountain and remote sites in Southern Nevada and California. To ensure that the conditions and requirements of all environmental permits, plans, and procedures were being fulfilled and applicable regulations were met, we conducted frequent, unannounced surveillance field checks. In Fiscal Year 1999, 540 such surveillances were conducted.



Archaeological survey near Yucca Mountain

In concert with the permitting process, we conduct surveys to inventory and protect ecological and cultural resources in areas proposed for surface-disturbing activities. Before work begins, specially trained personnel thoroughly examine these areas to identify important plant and animal species, such as the desert tortoise, and items of archaeological significance, primarily Native American artifacts, in the Yucca Mountain vicinity. In Fiscal Year 1999, we conducted six archaeological and six biological surveys before the start of work.

As stewards of the environment, and to adhere to the terms and conditions of our permits, we monitor air quality, meteorology, water quality, terrestrial ecosystems, and archaeological and Native American cultural resources to determine potential impacts from site characterization activities. To date, there have been no significant adverse environmental impacts. In Fiscal Year 1999, environmental data collection continued to support

repository design, biosphere modeling, total system performance assessment, and development of the draft EIS. The data will also support the determination on site recommendation.



Waste management survey

In compliance with the Programmatic Agreement between DOE and the Advisory Council on Historic Preservation, consultation and interactions with 17 Native American Tribes and organizations continued. At our invitation, Tribal representatives examined and evaluated nearly 400 artifacts for their significance under the Native American Graves Protection and Repatriation Act. A document presenting Native American perspectives on our Project and on the EIS was developed and used in preparation of the draft EIS.

Other efforts include terrestrial ecosystem studies and site reclamation. Information on these and other environmental program activities can be found in the *Site Environmental Report*, which is published annually and is available upon request from the Yucca Mountain Site Characterization Office.

Project Management

Reorganization of the Yucca Mountain Site Characterization Office, effective September 6, 1999, refocused functions related to Project management, planning, information systems management, and safeguards and security, in order to ensure adequate support for near-term goals, including support for determinations on site recommendation.

Project technical baseline changes

The repository system we are designing continues to evolve as our understanding of the natural setting grows and as we continue to enhance design concepts for engineered barriers. In Fiscal Year 1999, we produced or revised several technical baseline documents that define our understanding of the natural and engineered components of a repository system and ensure their thorough integration. Systems studies were completed to support decision-making on technical changes. We also modified the cost and schedule baseline and the work breakdown structure to reflect technical changes. We developed or upgraded Web-based information management tools to support efforts to integrate technical, cost, and schedule planning.

To implement the enhanced repository design concept, we revised the *Monitored Geologic Repository Concept of Operations* and the *Reference Design Description for a Geologic Repository* to include features associated with thermal management and emplacement operations, including installation of drip shields and use of backfill.

A baseline change was initiated for the *Monitored Geologic Repository Requirements Document* to incorporate Program-level changes to the *Civilian Radioactive Waste Management System Requirements Document*. The revision implemented requirements associated with adoption of the enhanced repository design concept: that the repository rock and drift wall temperatures be reduced, and that solar power be used for the subsurface ventilation system.

Project cost and schedule baseline changes

We revised the *Yucca Mountain Site Characterization Project Cost and Schedule Baseline* to reflect our new product-based work breakdown structure, to incorporate our new approach to documenting science and total system performance information for the site recommendation, and to reflect cost and schedule changes resulting from Fiscal Year 1999 planning.

The *Yucca Mountain Site Characterization Project Work Breakdown Structure* describes the “cost bins” for technical work. We revised the document to align it with Project work products: the site recommendation, the environmental impact statement, a license application, and a monitored geologic repository. Previous work breakdown structures were organized around functional areas (site testing, design, and performance assessment) and did not allow clear definition of the requirements and costs for the major products required by statutes and regulations. Clearly linking the cost baseline, its associated schedule, and the technical requirements for major products specified in the technical baseline will facilitate product-oriented planning over the next 5-year planning cycle.

External Oversight

As noted above, NRC plays a statutory role in the Civilian Radioactive Waste Management Program: it is responsible for licensing the repository and for issuing rules to govern licensing. NRC regulations also govern storage and transportation of radioactive materials.

The Nuclear Waste Technical Review Board also plays a statutory role: it was created by Congress to oversee our technical work. Composed of distinguished experts appointed by the President, it acts both as a full Board and through five panels organized around site characterization; the repository; the waste management system; the environment, regulations, and quality assurance; and performance assessment.

Meetings we held in Fiscal Year 1999 with NRC and the Board are listed in Appendix E. Publications the Board issued in Fiscal Year 1999 are listed in Appendix F.

Interactions with the Nuclear Regulatory Commission

Under the Nuclear Waste Policy Act, if the Secretary recommends to the President that the Yucca Mountain site be developed as a repository, the recommendation must include preliminary comments from the NRC to the Secretary on whether our site characterization analysis and proposed waste form appear sufficient to serve as the foundation for a license application. If Yucca Mountain is formally designated as the site of the Nation's first geologic repository, the Department must submit a license application to NRC.

The work of preparing for a determination on site recommendation also serves to develop the basis of a license application, but the application would be far more comprehensive, and the licensing proceeding would be among the most complex NRC has ever undertaken, requiring up to 3 years and entailing thousands of documents. None of DOE's licensed facilities approaches a geologic repository in complexity or the time frame for which safe performance must be demonstrated. Consequently, work to develop the basis for a license application

began some years ago, and our interactions with NRC have been important to developing a mutual understanding of both the Commission's expectations and our plans for presenting documentation of our findings and analyses. In Fiscal Year 1999, we revised our Technical Guidance Document for development of the license application.

NRC's strategic planning calls for early identification and resolution of issues at the staff level before a license application is submitted. To provide feedback on key issues, NRC has developed nine *Issue Resolution Status Reports* that define criteria for resolving each issue and that report on its status, including areas of agreement and NRC staff comments and questions. Fiscal Year 1999 meetings encompassed the results of the final peer review report on the total system performance assessment for the viability assessment, models of the natural system, total system performance assessment methodologies and results, models of the engineered system, and potential disruptive events that could affect repository performance.

On February 8, 1999, OCRWM's Acting Director briefed the Commissioners on the Program's status and the recently released viability assessment. In addition, three management meetings kept NRC informed of our overall progress and ensured that issues needing management attention were addressed. As we move closer to potential licensing, quality assurance issues become more central and, therefore, are discussed at management meetings. We are working to resolve concerns about quality assurance, and in Fiscal Year 1999, NRC continued to closely monitor our progress. More information on our quality assurance program is presented in Chapter 3.

For some years, NRC and the Department have been planning for an electronic licensing support network that would meet NRC requirements for electronic access to the unprecedented volume of documents required for a repository licensing proceeding. In December 1998, NRC published a final rule, 10 CFR 2 Subpart J, providing for electronic filing of documents and use of an Internet-based network that would enable all parties to repository licensing to share and access information through the Internet.

More information about NRC is available through its Web site at: www.nrc.gov

Interactions with the Nuclear Waste Technical Review Board

Pursuant to the Nuclear Waste Policy Act, as amended, the Nuclear Waste Technical Review Board must report its findings, conclusions, and recommendations to Congress and the Secretary of Energy at least twice a year. In April 1999, the Board released its *Report to the U.S. Congress and the Secretary of Energy*, summarizing its calendar year 1998 activities.

The Board stressed the importance of continuing to study the potential for water seepage into repository drifts, retardation of radionuclides in the unsaturated zone, long-term corrosion rates of waste package materials, and groundwater flow and radionuclide transport properties in the unsaturated zone. In our response to the Board, we reported our plans to continue seepage testing in the Exploratory Studies Facility main tunnel and in the cross-drift above it. We are continuing to study retardation of radionuclides in the unsaturated zone through tests at Busted Butte. We agreed that determining long-term corrosion rates of waste package materials is a high priority; we have been conducting such tests, for several years and have added data from other long-term tests to our databases. We agree that an important priority is understanding groundwater flow and the potential for radionuclide transport within the saturated zone under the repository to the geographic point at which compliance with radiation dose limits must be demonstrated. We are continuing to develop a three-dimensional flow and transport model with current data in an effort to reduce uncertainties.

The Board also expressed concerns about whether performance assessment models should assume that cladding on spent nuclear fuel would be a barrier to radionuclide migration. Our expert elicitation panel diverged on the issue of spent fuel cladding as a barrier to radionuclide migration, but it generally agreed there is not much information available on this topic. As a first step in resolving the issue, we undertook a detailed literature review involving

internationally known and respected experts on this subject. The review provided insight into the likely mechanisms that would be active under expected conditions, particularly late in the long life of the enhanced waste package. Several kinds of cladding integrity tests are under way at Argonne National Laboratory. Testing on crevice corrosion in cladding has been initiated.

The Board made several suggestions regarding our plans for developing a national transportation program. We will consider these suggestions when work in that area resumes.

In a separate report in April 1999 on the viability assessment, the Nuclear Waste Technical Review Board also stressed the merits of a cooler repository in reducing uncertainties about performance. As described previously, we evaluated alternative repository designs and selected a set of enhancements that conform to a number of the Board's recommendations. We reported on design work at the Board's January, June, and September 1999 meetings.

In Fiscal Year 1999, the full Board held three meetings. The first addressed the viability assessment, repository design, scientific investigations in the saturated zone, and Nye County's drilling program. The second focused on repository design and our study of enhanced design alternatives. The third focused on revision of the repository safety strategy, testing and analysis to support a site recommendation, model validation, and ways to enhance confidence in model results. EPA provided a summary of its proposed site-specific radiation protection standards for the Yucca Mountain site. In addition, the repository panel held a meeting on the design selection process for a license application.

More information about the Board, and the text of correspondence between the Board and OCRWM's Acting Director, is available on the Board's Web site at: www.nwtrb.gov

Relations with Affected Parties

Formal relationships

Under the terms of the Nuclear Waste Policy Act, the State of Nevada, Nye County, and nine contiguous counties, including Inyo County in California, are entitled to exercise oversight of site characterization activities and to receive financial assistance for this purpose. In Fiscal Year 1999, Congress continued to provide financial support for oversight efforts by the 10 affected counties and the State of Nevada: it provided \$5.54 million to the counties and \$250,000 to the State.

County’s oversight program can be found through its Web site, at: www.nyecounty.com

During the fiscal year, we continued interactions with the ten affected counties and the State. Project staff hosted two meetings in Las Vegas with county representatives. We also provided Project updates to the County Commissions, Boards of Supervisors, and State and local government committees, and we conducted 29 site tours for community, county, and State officials.

Recipient	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000 Plan
Churchill	70,000	111,386	200,000	200,000	0	0	178,000	197,224	193,379
Clark	1,508,550	2,227,722	2,430,000	2,430,000	0	0	1,300,000	1,440,400	1,412,320
Esmeralda	125,000	185,644	210,000	210,000	0	0	178,000	197,224	193,379
Eureka	70,000	148,515	200,000	200,000	0	0	178,000	197,224	193,379
Lincoln	327,900	475,248	544,000	544,000	0	0	582,500	645,410	632,828
Inyo	135,000	289,604	386,000	386,000	0	0	374,500	414,946	406,858
Lander	70,000	111,386	200,000	200,000	0	0	178,000	197,224	193,379
Mineral	70,000	111,386	200,000	200,000	0	0	178,000	197,224	193,379
Nye	1,508,550	2,227,723	2,430,000	2,430,000	0	0	1,675,000	1,855,900	1,819,720
White Pine	70,000	11,386	200,000	200,000	0	0	178,000	197,224	193,379
Total AULG	4,000,000	6,000,000	7,000,000	7,000,000	0	0	5,000,000	5,540,000	5,432,000

Oversight financial assistance payments to the ten affected counties

The Nuclear Waste Policy Act also gives the State and Nye County 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 Nye County has, and its representatives continued to oversee our work in Fiscal Year 1999. As reported previously, Nye County implemented its Fiscal Year 1999 initiative to drill boreholes near Amargosa Valley. Sampling and data collection are yielding needed information about water flow and fault structure in the saturated zone. OCRWM provided Nye County \$3.6 million in Fiscal Year 1999 for this program. Information about the



Meeting with local government representatives

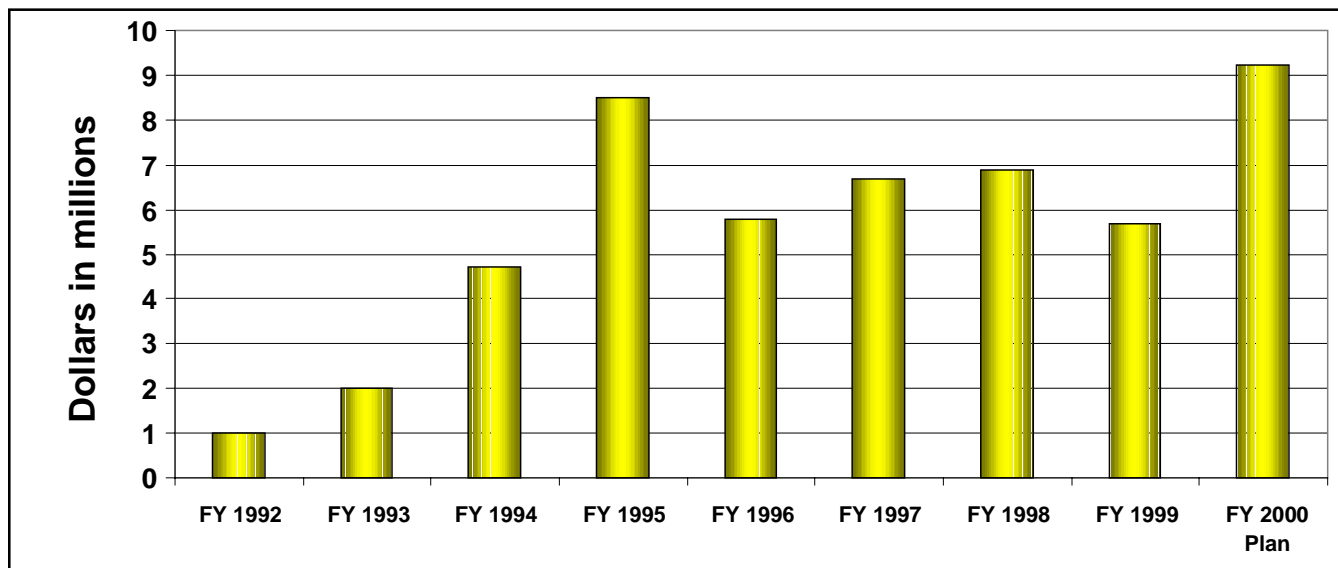
We continued funding our Payments-Equal-to-Taxes (PETT) agreement with the State of Nevada and Nye, Clark, Esmeralda, Lincoln, and Inyo Counties. Under Section 116(c)(3) of the Nuclear Waste Policy Act, these payments are intended to compensate for taxes that affected entities would have collected on site characterization and the development and operation of a repository if they were authorized to tax Federal Government activities. A total of \$5.7 million was provided in Fiscal Year 1999, of which \$5 million went to Nye County.

In Fiscal Year 1998, the Yucca Mountain Site Characterization Project and the University and Community College System of Nevada entered into a cooperative agreement for conducting scientific studies that could augment our own studies by expanding scientific data on the Yucca Mountain site or filling data gaps. Under this agreement up to \$40

packages. Studies will also contribute geochemical data for development of the single regional groundwater model described above.

Yucca Mountain Site Characterization Project Outreach

To provide timely and accurate information about the Yucca Mountain Site Characterization Project, we maintained an active communication program in Las Vegas, Nevada. We reached stakeholders, interested groups, and members of the public through a variety of means: newsletters and fact sheets; a toll-free information number; science centers; and correspondence. Our Web site remained one of our most important tools for this purpose. Through a speakers' bureau, tour program, exhibits at key events, and meetings, we promoted two-way communication with technical audiences and the general public.



Historical profile of Payments-Equal-to-Taxes

million may be applied to such studies for Fiscal Years 1998 through 2002; through Fiscal Year 1999, \$6.2 million had been provided. Subjects of the studies include geophysical strain accumulation in the Yucca Mountain area, fluid inclusion in rock fracture fillings, seismicity, water infiltration through the site, and the potential for seepage into repository drifts and waste

In Fiscal Year 1999, we conducted more than 250 tours of the Yucca Mountain site, briefing more than 4,300 visitors. Our exhibit was seen by nearly 10,000 people at 20 meetings held throughout the United States. Through our speakers' bureau, we made 85 presentations to civic, educational, business, and professional groups, reaching more than 4,800 people.



Yucca Mountain exhibit



Visitors in Alcove 2



Yucca Mountain exhibit



Yucca Mountain tour group

We answered more than 13,500 phone calls and letters, providing written responses and Project literature. We also filled 2,200 requests for documents, shipping more than 31,900. Our three Nevada Science Centers hosted 9,880 visitors. Our Web site was heavily visited by individuals and by business, educational, and government entities around the world.

In educational settings, we reached over 8,500 Nevada students in kindergarten through twelfth grade and

more than 300 Nevada teachers and parents. These activities included workshops on energy, geology, and environmental studies; classroom presentations; field trips; science discovery days; scout merit badge workshops; and participation in the JASON Project, a nationwide, interactive science program.

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