Chapter One

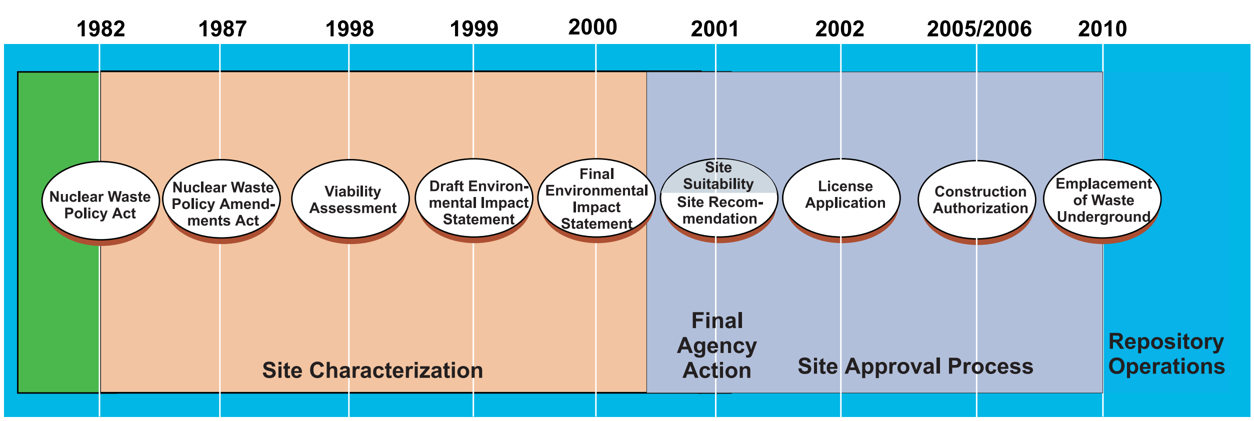
Yucca Mountain Site Characterization Project

Introduction

Located 100 miles northwest of Las Vegas on remote and semiarid Federal land, Yucca Mountain has for 15 years been the subject of comprehensive studies. Broad in scope and intricate in detail, those studies are designed to yield information that will support a series of decisions about whether a geologic repository for spent nuclear fuel and high-level radioactive waste should be developed at the site. Fiscal Year 1998 was dominated by preparation of the *Viability Assessment of a Repository at Yucca Mountain.* The viability assessment presents the first comprehensive description of a potential repository at that site and of its expected performance in minimizing potential radioactive dose levels to nearby residents over thousands of years. On December 18, 1998, the Secretary of Energy submitted the viability assessment to the President and to Congress and released it to the public.

Required by Congress, the viability assessment served as a valuable management tool: preparing it helped clarify, integrate, prioritize, and advance the scientific, design, and performance assessment work necessary to meet statutory requirements. (See figure below.) In the course of the year, we benefited from continued reliance on expert elicitation and independent peer review; the contributions of the Nuclear Waste Technical Review Board, which oversees the technical and scientific aspects of our work; and interactions with the NRC, which has statutory responsibility for licensing a geologic repository for high-level radioactive waste and spent nuclear fuel.

The year closed with a reorganization of our Yucca Mountain Site Characterization Office, which took effect October 1, 1998. Described in Chapter Three, it responds to the shift in our focus from scientific investigations that generated data needed for analyses and initial design work, to the



Statutory milestones leading to waste emplacement

tasks of closing out scientific issues, closing out design options, and developing major work products. Those products are (1) an environmental impact statement and other information needed to support a Secretarial decision in 2001 on whether to recommend the Yucca Mountain site to the President for development as a repository, and (2) if the site is recommended and approved, a license application to be submitted to the NRC in 2002.

The Viability Assessment

Contents of the viability assessment

In 1996, the Department announced that it would prepare a viability assessment of the Yucca Mountain site, and in its 1997 Energy and Water Development Appropriations Act, Congress formally directed the Department to do this. A comprehensive statement of what we had learned from site characterization and what would be required to prepare a license application to the NRC, the viability assessment was designed to give policy makers the information they need to assess the prospects for geologic disposal at Yucca Mountain.

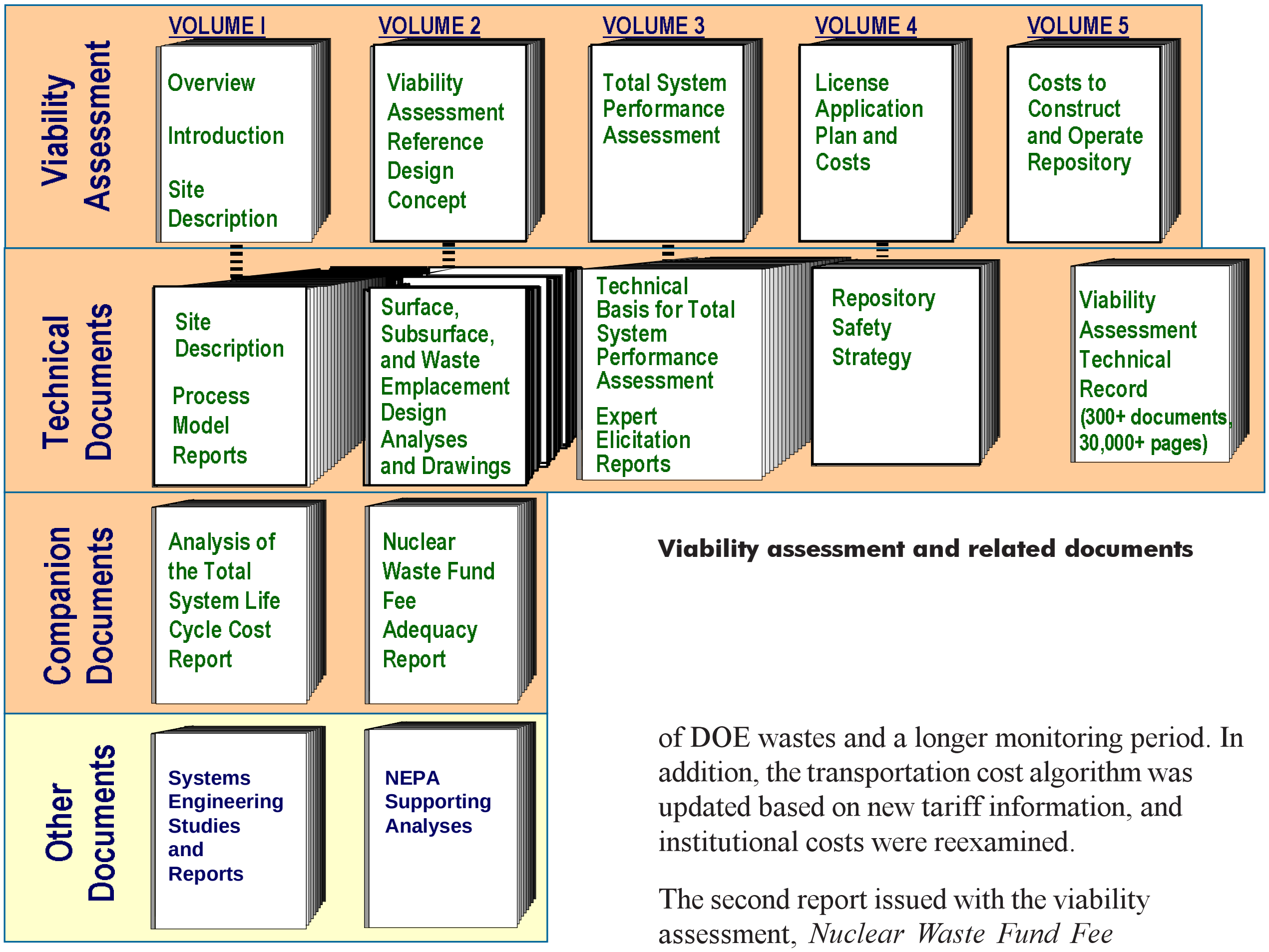
The five volumes of the viability assessment present (1) a site description; (2) a reference design for the repository and waste package; (3) a total system performance assessment that builds on total system performance assessments conducted in 1991, 1993, and 1995; (4) a plan and cost estimate for work remaining to complete a license application; and (5) an estimate of the cost to construct, operate, monitor, and close a repository based on the reference design. The viability assessment is accompanied by two reports: a total system life-cycle cost analysis (TSLCC) that updates the analysis conducted in 1995, and the annual fee adequacy assessment, based on the new TSLCC. The viability assessment is also supported by a number of technical documents.

Findings presented in the viability assessment

Preparing the viability assessment engaged participants across the Program in a thorough review of 15 years of work. Based on the results of the viability assessment, DOE believes that work should proceed to support a decision in 2001 on whether to recommend the Yucca Mountain site to the President for development as a repository. For the site to be recommended, DOE must demonstrate that a repository designed for and built at Yucca Mountain would protect public health and safety and the environment for thousands of years. The viability assessment identifies the seepage of moisture into repository tunnels, termed *drifts*, and onto waste packages as the most significant factor affecting waste package degradation and release of radionuclides. It forecasts the range of likely radiation doses to nearby residents over thousands of years to be very low. The cost of preparing a license application is estimated to be $1.1 billion, with the total cost of repository development ranging from $16.3 to $19.8 billion, depending on the length of the monitoring period after waste emplacement ends.

Findings presented in companion reports

Two reports were issued as companion documents to the viability assessment. *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program* reflected significant changes in OCRWM's Program since the previous TSLCC was conducted in 1995. The TSLCC analysis is based on design concepts used in the viability assessment and provides a comprehensive cost estimate for disposal of all wastes projected through the year 2035. Besides including all costs identified in the viability assessment, the TSLCC includes historical costs, and the costs of transportation, construction of a rail spur in Nevada, and certain institutional, program integration, and management cost



Viability assessment and related documents

categories not included in the viability assessment.

From 1983 through 1998, total program costs were $5.9 billion in historical dollars; the 1998 TSLCC projects a total future cost to complete the Civilian Radioactive Waste Management Program, through repository closure in 2116, of $36.6 billion in constant 1998 dollars. Although elimination of extensive use of multi-purpose canisters lowered cost projections in the 1998 TSLCC, this decrease was offset by an increase in disposal container and surface facility costs. Other cost increases resulted from planned disposal of larger quantities of DOE wastes and a longer monitoring period. In addition, the transportation cost algorithm was updated based on new tariff information, and institutional costs were reexamined.

The second report issued with the viability assessment, *Nuclear Waste Fund Fee Adequacy: An Assessment,* is based on the 1998 TSLCC. Because the owners and generators of commercial spent nuclear fuel must pay the full costs of disposing of it, the Act requires an annual assessment of whether the fee they pay into the Nuclear Waste Fund is adequate to cover those costs. The 1998 assessment considers a reasonable range of uncertainties in projecting what the Fund's balance would be at the end of the Program's life, and it concludes that the fee is adequate to provide a margin of safety for uncertainties and changes in program scope, cost, revenues, and economic assumptions. The fee has remained unchanged since it was established by the original Act at 1.0 mil per kilowatt hour of electricity generated and sold.

Until updated, the 1998 TSLCC will support future fee adequacy analyses and will serve as the basis for calculating the Government's share of disposal costs for DOE-managed nuclear materials.

Updating the Regulatory Framework for Repository Development

The Nuclear Waste Policy Act of 1982 required that a regulatory framework govern certain statutory decisions about repository development. The Nuclear Waste Policy Amendments Act of 1987 and the Energy Policy Act of 1992 changed the statutory requirements that apply to the siting and licensing of a geologic repository at Yucca Mountain. The Environmental Protection Agency (EPA) and the NRC are engaged in efforts to update their respective implementing regulations, as described below. Those implementing regulations must be in place for the Program to proceed to the next statutory milestone, the Secretary's decision on site recommendation.

Environmental Protection Agency standards

The Energy Policy Act of 1992 directed EPA to issue site-specific public health and safety standards for a repository at Yucca Mountain. These standards would establish limits on annual radiation doses to individual members of the public from repository releases. These standards are to be based on and consistent with findings and recommendations of the National Academy of Sciences. EPA contracted with the Academy for these findings and recommendations, and the Academy issued its report in 1995. EPA is expected to publish a proposed rule for site-specific health and safety standards in Fiscal Year 1999.

Nuclear Regulatory Commission requirements and criteria

The Nuclear Waste Policy Act of 1982 directed the NRC to establish technical requirements and criteria for the approval or disapproval of applications to construct repositories, licenses to receive and possess spent nuclear fuel and high-level radioactive waste, and authorizations to permanently close repositories. Under the Energy Policy Act of 1992, the NRC is to modify its requirements and criteria as necessary to be consistent with the standards that EPA issues specific to Yucca Mountain. In Fiscal Year 1998, the NRC staff proposed, and the NRC subsequently approved, the development of a new regulation at 10 CFR 63, to contain site-specific requirements for a repository at Yucca Mountain. Because of the short time frame permitted by the Act, the NRC has proceeded to develop its rulemaking in parallel with development of the EPA standards. Thus, on February 22, 1999, the NRC issued a proposed rule entitled "Disposal of High-Level Radioactive Wastes in a Proposed Geological Repository at Yucca Mountain, Nevada" 64 Fed. Reg. 8640 (1999). The NRC may need to amend the proposed rule when the EPA issues its final standards, or if new legislation is enacted that affects the disposal standard.

The Repository Safety Case

Will a repository system built at Yucca Mountain be safe? This is the principal question that the Administration, Congress, and the public want answered. Regulatory standards, now undergoing revision at the direction of Congress, will establish a limit to the radiation dose to which future residents near the site could be exposed. The work of site investigators is to further understanding of the natural features of the site and how they could affect dose levels. The work of repository designers is to design engineered barriers that would function in concert with the natural barriers at the site to keep dose levels below the limits established.

Performance assessment modelers determine how well the natural features and engineered barriers would function together in first containing radionuclides for many thousands of years and then limiting their release and transport so that any eventual dose to which a member of the public could be exposed would be below the limits established to protect the public. This modeling helps identify uncertainties in our understanding of repository performance, how much each uncertainty matters, and where more data from site investigations, or more robust engineered barriers, can help compensate for some of them.

Making the case

If the Secretary is to decide to recommend the site, and if the NRC is to authorize construction, OCRWM must demonstrate that a repository system at Yucca Mountain can be reasonably expected to keep radiation doses at levels below the regulatory limit. In preparing the viability assessment, we formally defined the set of arguments that we would develop to support such a demonstration based on the repository reference design selected for that assessment. This *safety case* takes into account a number of factors: the expected performance of the repository system, the design-margin and defense-in-depth provided by the components of the system, the potential effect of disruptive processes and events on system performance, insights from natural and man-made analogs that help to confirm our understanding of long-term behavior, and the effectiveness of measures planned to provide confirmation of our assumptions about repository performance.

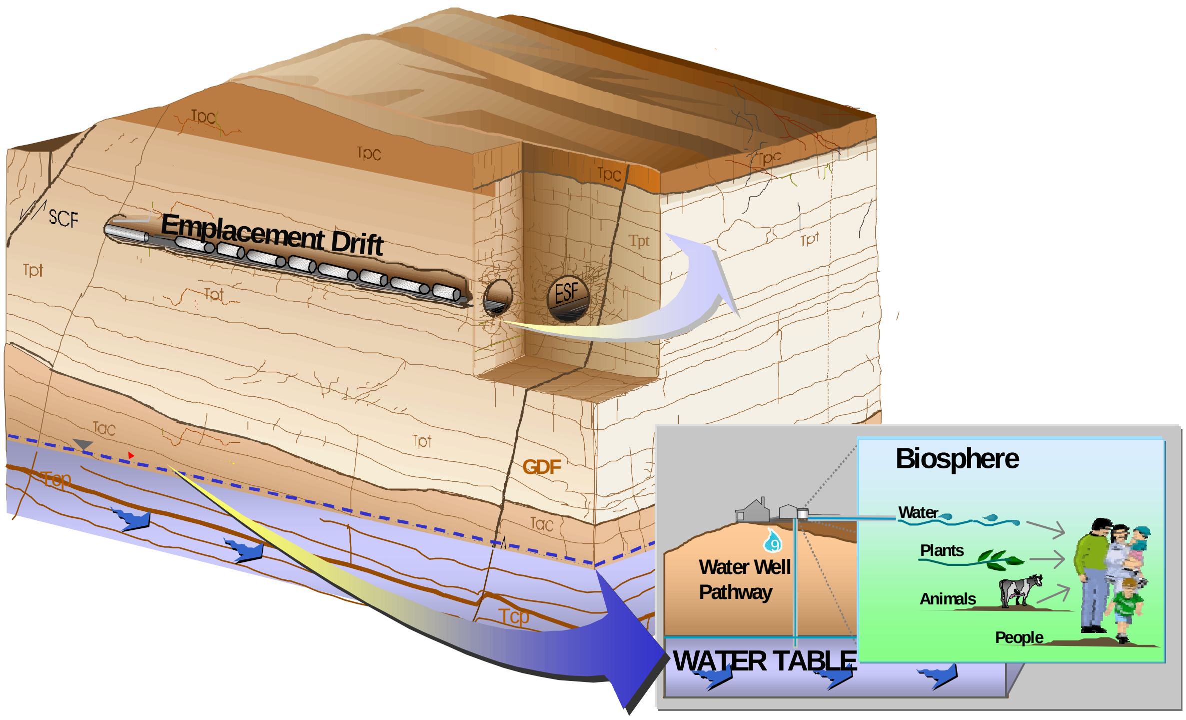
The 1998 repository safety strategy

Integral to the postclosure safety case is a repository safety strategy. First issued in Fiscal Year 1996, it was revised in 1998 to reflect what we had learned from various efforts: recent scientific investigations of the site; work to develop design of the engineered system for the viability assessment; total system performance assessment iterations conducted in 1991, 1993, and 1995; and the total system performance assessment conducted in 1998 for the viability assessment.

The current repository safety strategy rests on assumptions about the four key attributes of a repository system in the particular geologic setting of Yucca Mountain. In that setting, the repository host rock within which waste would be emplaced lies approximately 300 meters (1,000 feet) below the surface of the Yucca Mountain site and approximately 300 meters (1,000 feet) above the water table. The key attributes were defined through analysis of information about the site and about the likely performance of the engineered components of the system. They relate to the characteristics of the natural system, as well as to the physical characteristics of materials that may be part of the engineered system, and to the important interactions between the natural and engineered systems. The key attributes are the following:

- 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

The repository safety strategy also rests on an evolving understanding of the related factors important to assessing how the repository system would perform for thousands of years after it was closed. Understanding the factors related to each of the key attributes above enables us to design engineered barriers that can augment the performance of the natural system in delaying radionuclide release and transport. Taken separately, the attributes help define the bases for the work needed to complete the postclosure safety case. Taken together, they constitute a



Repository cutaway with waste packages, water table, path to accessible environment

conceptual framework for assessing the overall performance of a repository system at Yucca Mountain.

The repository safety strategy and the work to complete the postclosure safety case are focusing our efforts on a more limited set of testing, design, and analysis activities. Both were considered in developing Volume 4 of the viability assessment, which describes the work necessary to support a decision on site recommendation and preparation of a license application. Further revision of the safety strategy is contemplated in 1999 to reflect the additional perspectives gained as a result of the design and performance assessment work done in preparing the viability assessment.

Changes to the strategy may also be needed to reflect specific elements of the design selected as the basis for decisions about site recommendation and licensing.

Performance Assessment

The determination of site suitability and repository licensing will rely in large measure on the application of performance assessment: the modeling that integrates data from site investigations, laboratory testing, and expert opinion with information about repository design, to simulate the behavior of the repository system under a range of conditions and a variety of design options over thousands of years. In turn, results of modeling and sensitivity studies identify those uncertainties important to repository performance and indicate where more data are needed to reduce uncertainties or where alternative design features can compensate for them.

One of the five volumes of the viability assessment was devoted to total system performance assessment. Future total system performance assessment analyses will support the Secretary's decision on site recommendation and, if the site is recommended and approved, will provide the basis for demonstrating compliance with postclosure requirements in a licensing proceeding. Those total system performance assessment analyses will reflect both new information gained from site investigations and advances in design work.

In Fiscal Year 1998, we continued the performance assessment work we had begun in Fiscal Year 1997, as described below.

Expert elicitations

Uncertainties in our understanding of natural processes, and in the models used to represent them and the parameter values used to bound them, are a central focus of performance assessment. To help quantify them, we relied upon expert elicitations on the subjects of waste package degradation, waste form dissolution, transport within the engineered barrier system, and the near-field environment.

Each elicitation entailed these steps: (1) defining process model inputs to total system performance assessment; (2) selecting experts to provide interpretations; (3) meeting to identify issues, data needs, methods, and interpretations; (4) compiling and disseminating data to the experts; (5) eliciting expert interpretations; (6) reviewing and finalizing interpretations; (7) calculating and aggregating interpretations; and (8) documenting the results.

By properly and comprehensively capturing uncertainties in the process models and the data that support them, in a form useful for total system performance assessment, the elicitations helped us develop and refine process model descriptions that provided technically defensible products that could be abstracted for use in the total system performance assessment conducted for the viability assessment.

Independent peer review

Since January 1997, a total system performance assessment peer review panel has been closely examining our work in order to present formal, independent evaluations and critiques of our development of the total system performance assessment for the viability assessment. The panel was formed to help us make our total system performance assessment transparent to technical peers, regulatory and oversight bodies, and Administration and congressional decision makers, and to help ensure the traceability of decisions and assumptions that support the viability assessment.

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

The panel has been evaluating our analytical approach, including physical events and processes considered in analyses, use of appropriate and relevant data, assumptions made, abstraction of process models into total system models, application of accepted analytical methods, and

Background on Total System Performance Assessment

Simple questions, complex answers

Will the proposed repository system protect public health and safety? How adequate is our understanding of how the system will perform? What do we need to do to reduce uncertainties in our understanding? Where we cannot reduce uncertainties, how much do they matter, and how sensitive are they to change?

While such questions may appear simple, the task of answering them is not. To formulate, explore, and narrow a range of answers, scientists use an analytic modeling tool called *performance assessment*. Using data from site investigations, modelers create conceptual models of features, events, and processes associated with the site, and, in some instances, alternative conceptual models. Conceptual models are then synthesized into numerical models of how natural geologic, hydrologic, geochemical, and geomechanical processes behave over time. These process models are used to enhance understanding of controlling natural processes, such as moisture movement in the unsaturated zone, and to provide estimates of parameter values, such as percolation flux at the repository horizon.

Total system performance assessment builds on these analyses to represent all significant site features, events, and processes in models that together can be used to forecast the long-term behavior of the repository system. Total system performance assessment must capture all important components of the engineered and natural barrier system. It must also evaluate uncertainty in the forecast and the implications for human health and safety associated with uncertainty in (1) site characterization information, (2) conceptual models of subsystem performance, and (3) process models and parameters.

Typically, because process models tend to be quite complex and involve extensive computation, to provide input to a total system performance assessment model, the process models and/or their results are abstracted: their essential components are simplified while their intrinsic form is retained. The results must reproduce or bound those of the underlying process models, which are based on data about the site. The abstracted models for each subsystem are then combined into a total system performance assessment model.

treatment of uncertainty. The panel reviewed supporting documentation, such as process-level models; attended technical meetings; and reviewed documentation for the total system performance assessment as it was being prepared. As timing permitted, the panel's comments, findings, concerns, conclusions, and recommendations contributed to our development of the total system performance assessment. What we learn from the panel will be factored into development of total system performance assessment models used to support a decision on site recommendation and a license application, if one is submitted.

Phase Two of the panel's work was completed in December 1997; Phase Three was completed in June 1998; Phase Four, which entails review of the documentation that supports the total system performance assessment conducted for the viability assessment, was completed in February 1999.

Modeling, analysis, and documentation

A major effort centered on refining our total system performance assessment methodology and models, conducting detailed analyses, and clearly

By simulating the performance of the repository system and determining the effects of uncertainty, scientists can identify where more information is needed to further their understanding, and where that information matters. As more data are generated through scientific investigations and design work, they are used to refine total system performance assessment models.

Simple goals, complex challenges

Technical validity is an obvious goal. A model is considered technically valid if it provides a sufficiently accurate representation of the process or system of processes being addressed. Evaluating this accuracy and its sufficiency is a complex task that must take into account processes that operate at micron scales as well as kilometer scales, over many thousands of years. To meet this complex challenge, we employ independent evaluations of our models and conclusions by comparing our predictions against the actual results of field observations and laboratory testing. We also conduct studies of analogs.

But technical validity alone is not sufficient. Other goals are to make the work defensible and understandable. This means a total system performance assessment must be *transparent*, supported by clear and logical documentation that will make every significant element of the work clear not only to technical analysts but to other informed reviewers. A total system performance assessment must also be *traceable*, supported by a complete and unambiguous record of decisions and assumptions, and of models and data, and of how they were used to arrive at results. Achieved through documentation and explanation of all decisions made during the analyses, traceability competes to an extent with transparency: a fully traceable account of a system assessment may be so voluminous as to be opaque to an interested non-specialist. For the viability assessment, we tried to satisfy both these demands by preparing a summary of our total system performance assessment work that is several hundred pages long and also publishing a far more detailed account in a technical basis report that is thousands of pages long.

documenting our efforts, so that total system performance assessment results would warrant high confidence. Using input from multiple sources, we refined abstracted subsystem models for features, events, and processes that could affect repository performance. Sources included data from site investigations, regional studies, design work, expert elicitations, and peer review findings. We also developed new preliminary abstracted models to assess processes not previously considered. For example, we developed and added to total system performance assessment analyses a model for colloidal transport of plutonium and a model that takes into account the fact that the Zircaloy cladding that contains spent nuclear fuel may affect the release of radionuclides. The abstracted models were combined into a total repository system model. Further work is under way to develop stronger abstracted models in all areas.

Analyses were conducted for several purposes:

- We analyzed models to forecast repository performance for three time frames (10,000, 100,000, and 1 million years); for a wide range of conditions, to reflect uncertainty in the present state of our knowledge and its consequences; and to examine impacts to individuals residing 20 kilometers away from the site.

- We examined the impacts of uncertainty on total system performance. The results helped us decide where we should allocate resources for work that will reduce uncertainty in areas important to performance.
- We examined how design options such as drip shields, ceramic coating, and backfill can impact repository system performance.

All of these analyses are ongoing.

Traceability and transparency are essential to demonstrating the credibility of our work, and the Nuclear Waste Technical Review Board had recommended that we bolster them in the viability assessment. In preparing the total system performance assessment volume of the viability assessment, we made providing traceability and transparency for our analyses a paramount concern. This presented a challenge when it came to describing abstracted models and explaining their basis in process-level models. To meet this challenge, we summarized the abstraction work in Volume 3 of the viability assessment and documented the work thoroughly in a much longer report, *Total System Performance Assessment - Viability Assessment Technical Basis Report.* Both documents were made available on the Internet and published in printed form.

Total system performance assessment assumption about the quantity of waste to be emplaced

The total system performance assessment base case defined the amount of waste to be emplaced in the repository as 70,000 metric tons heavy metal (MTHM). While the total projected inventory of materials requiring geologic disposal significantly exceeds that figure, the Nuclear Waste Policy Act prohibits, at Sec. 114(d), "the emplacement in the first repository of a quantity of spent fuel containing in excess of 70,000 metric tons of heavy metal or a quantity of solidified high-level radioactive waste resulting from the reprocessing of such a quantity of spent fuel until such time as a second repository is in operation." In 1987, amendments to the Act terminated all work on a second repository and required the Secretary to report to the President and to Congress on or after January 1, 2007, but not later than January 1, 2010, on the need for a second repository. It appears that the Yucca Mountain site can accommodate more than 70,000 MTHM, and OCRWM is designing the repository to accommodate the entire projected inventory of materials requiring geologic disposal, so that future decisions about the need for a second repository could take into account the maximum physical capacity of the Yucca Mountain site. However, if the site is developed as a repository, the amount of waste emplaced in it would be determined by the statute, regulations, or licensing requirements in effect at that time.

Factoring DOE-managed nuclear materials into our assessments

To obtain NRC authorizations for a repository that will hold DOE-managed nuclear materials, we must demonstrate how these materials would affect repository performance. This means that we need specific data on the physical, chemical, and nuclear properties of these materials, including the over 250 forms of DOE spent nuclear fuel, which is far more heterogeneous than commercial spent nuclear fuel. In Fiscal Year 1998, the total system performance assessment conducted for the viability assessment considered the characteristics of all waste forms in some manner.

For the base case total system performance assessment analysis, 63,000 MTHM of the 70,000 MTHM assumed to be emplaced is allocated to commercial spent nuclear fuel. The remainder is allocated to 7,000 MTHM-equivalent of

DOE-managed nuclear materials, of which approximately two-thirds is high-level radioactive waste in the form of borosilicate glass logs and approximately one-third is DOE and naval spent nuclear fuel.

While plutonium waste forms were not explicitly treated in the total system performance assessment base case, they—along with individual categories of DOE spent nuclear fuel—were explicitly treated through sensitivity analyses. The sensitivity analyses considered the two plutonium waste forms currently under consideration by the Department: mixed oxide (MOX) spent nuclear fuel and plutonium immobilized in a ceramic matrix. The analyses indicated that the contribution of these waste forms to the total radiation dose to the public is bounded by the dose from an equivalent amount of commercial spent nuclear fuel or vitrified high-level radioactive waste.

The environmental impact statement (EIS) that will support the Secretary's decision on site recommendation will also evaluate these waste forms for disposal in the repository. The base case for the EIS will assume that 70,000 MTHM will be emplaced in the repository; additional inventory modules will include assumptions of more than 70,000 MTHM, different thermal loading scenarios, and different waste emplacement locations.

New Construction: the Cross-Drift and Busted Butte

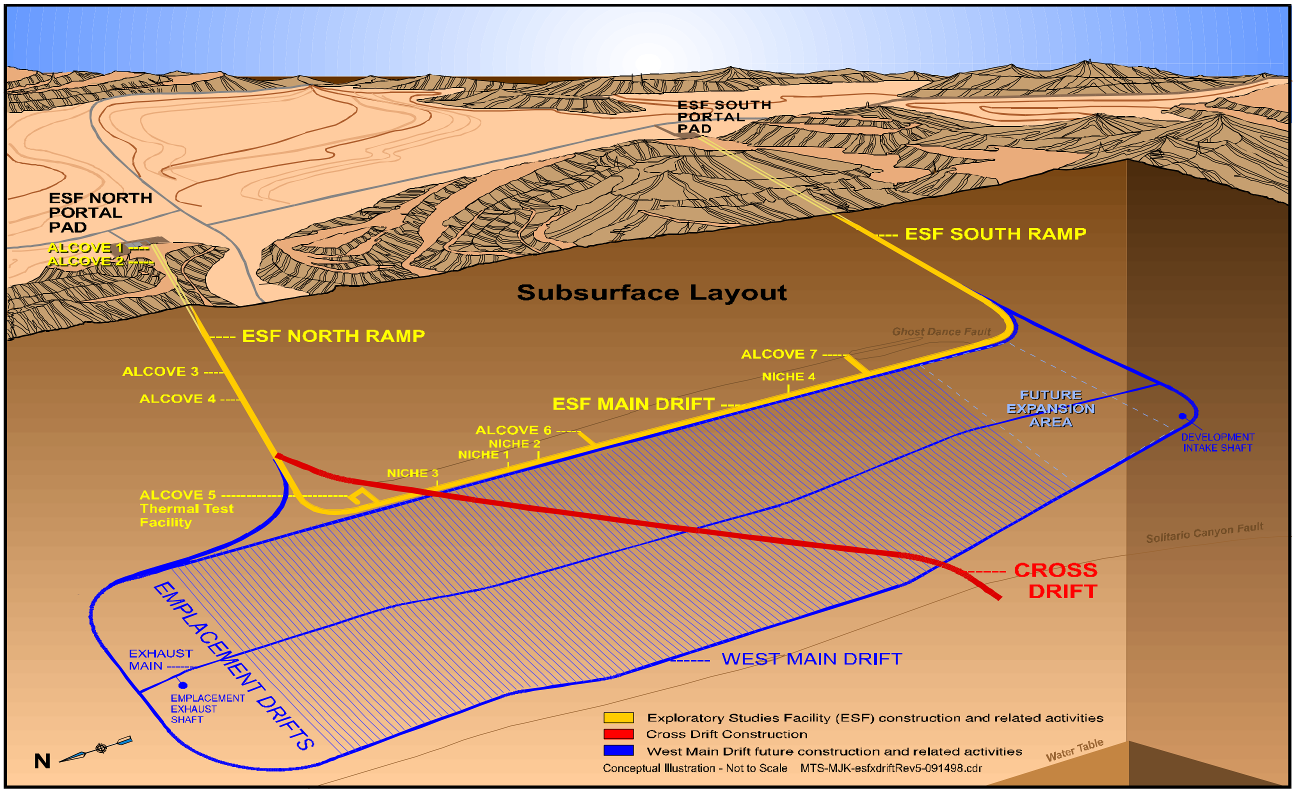
As total system performance assessment more narrowly defined uncertainties that could significantly affect dose levels, site investigations and laboratory studies focused more narrowly on generating data that could reduce those uncertainties. Of particular interest were these phenomena:

- *Heat: effects on rock and water.* How would heat generated by radioactive decay of the waste alter the surrounding environment? In turn, how could changes in that environment affect the rate at which waste packages degrade and radionuclides are released, and the mechanisms and pathways by which radionuclides could be transported?
- *Seepage: mechanisms, quantity, and rate.* Under what conditions, in what quantities, and at what rates would moisture seep into drifts and onto waste packages, degrading the packages and creating the potential for transport of radionuclides released from them?
- *Radionuclide transport: mechanisms, quantity, and rate.* Beyond the near-field environment, by what pathways and mechanisms, and at what rate, could radionuclides be transported? What phenomena (such as the solubility limits of specific radionuclides, dispersion and diffusion during transport, and dilution) could minimize resultant dose levels?

Testing to pursue these inquiries has been conducted for many years from the surface of the site and in off-site laboratories. Construction, over a period of 5 years, of the Exploratory Studies Facility—a nearly 8-kilometer- (5-mile)-long underground laboratory—permitted a vast expansion of testing. In Fiscal Year 1998, two construction projects were undertaken to further accelerate and bolster basic lines of research: excavation of a cross-drift from within the Exploratory Studies Facility and construction of a test facility at Busted Butte. Testing at these new locations has been yielding valuable data and is expected to continue for several years.

Completion of the cross-drift

Our project scientists, engineers, and performance assessment modelers all wanted information about the repository horizon, and the Nuclear Waste Technical Review Board had recommended that we obtain it. We had therefore planned to excavate a tunnel that would begin within the



Schematic of cross-drift

north ramp of the Exploratory Studies Facility and cross the repository block. The initiative was termed *enhanced characterization of the repository block;* the tunnel itself came to be known as the *cross-drift.*

The 2.68-kilometer- (1.67-mile) cross-drift was designed by a working group of scientists, engineers, and modelers who defined 33 technical criteria that satisfied their joint needs. Design decisions were tested against the criteria, and the orientation and configuration of the cross-drift were determined accordingly. By cutting across the entire stratigraphic section of the potential repository, the cross-drift provides a more complete three-dimensional view of Yucca Mountain and permits scientists and engineers to examine fracture patterns, potential faults, distinct rock layers, and various hydrologic characteristics in the area in which waste would actually be emplaced. It is yielding valuable information about basic rock units, their contact with each other, and their structure. Excavation of the cross-drift also furthered our understanding of subjects that would bear on actual repository construction: engineering for and construction of the facility, health and safety concerns, costs, and regulatory compliance.

The drift was excavated by a 225-ton tunnel boring machine with a diameter of 5 meters (16 feet 5 inches). To position the tunnel boring machine to excavate the drift, a launch chamber was constructed within the Exploratory Studies Facility, at a location almost 2 kilometers (1.25 miles) from its northern entrance. Excavation of the launch chamber began in December 1997, ahead of schedule. The tunnel boring machine was delivered in parts and partially assembled outside

Cross-drift conveyor system with dust-suppression equipment

and above the water table. Because it is not an analog site, but an extension of the geologic units that compose the area in which the repository would be constructed, it can yield insights into how the structure and mineralogy of that crucial zone could affect the transport of radionuclides. Of particular interest is the Calico Hills formation, which contains zeolites: clay minerals resulting from alteration of the original volcanic rock. Because some radionuclides strongly sorb to zeolites, scientists believe that zeolites in the unsaturated rock beneath the repository would retard the transport of radionuclides to the water table and on

Geologists using the mapping platform in the cross-drift

the launch chamber, then transported into the chamber, where assembly was completed.

Construction of the cross-drift itself began in March 1998. During excavation, fractures and faults were mapped at a short distance behind the tunnel boring machine. Care was taken to protect the integrity of the adjacent Exploratory Studies Facility. By the end of Fiscal Year 1998, we had crossed the repository block; by October 13, 1998, construction was completed, and several alcoves, including a thermal test alcove, and two niches that will be used for testing, remained to be constructed.

A new test facility at Busted Butte

Busted Butte is a particularly valuable test location. A small hill approximately 5 kilometers (3 miles) south of Yucca Mountain, it consists of the same geologic formation, the Calico Hills, as the rock beneath the potential repository horizon to the accessible environment. Moreover, the Busted Butte test facility exposes the point of contact between the Calico Hills formation and the Topopah Spring tuff formation, which contains the potential repository horizon. These two geologic units possess significantly different hydrologic and geochemical properties; together, they constitute an important part of the natural barriers to radionuclide transport to the accessible environment.

Previous knowledge of how radionuclides might behave in this formation had been gained largely by conducting laboratory tests on rock samples taken from the formation. To gain field-scale knowledge of Busted Butte and accelerate field-scale testing in the unsaturated zone, we designed a three-phase study employing hydrologic testing and non-radioactive tracer tests. The data generated will help scientists better understand potential radionuclide retardation and colloid migration within these formations and the characteristics of groundwater flow under unsaturated conditions. Scientists can also use the data to validate conceptual models of groundwater flow and radionuclide transport in the unsaturated zone, and determine the applicability of transport parameters derived from laboratory testing to the actual site.

Construction at Busted Butte face

In December 1997, we began construction of a test facility at Busted Butte. The 85-meter (280-foot) tunnel and an instrumentation alcove were completed in February 1998. The main test block is 10 meters by 10 meters by 5 meters (33 by 33 by 16.5 feet). Within it, 36 boreholes totaling 271 meters (over 894 feet) in length were drilled for use in injection and collection of tracer materials and for tomography tests that generate data that can be used to construct a three-dimensional numerical model of how moisture migrates in response to fluid release from pore space and mechanical response of the host rock to thermal loading.

enable them to compare actual data with their models and to calibrate models as necessary.

Laboratory tests using real and simulated radionuclides are being conducted concurrently at Los Alamos National Laboratory. By comparing results from combined field and laboratory tests

Busted Butte test alcove

The alcove and boreholes were instrumented and Phase 1 tests began in March 1998; Phase 2 tests began in July. Using various geophysical techniques, scientists gathered tracer migration data in real time, and they used it to create the three-dimensional map of tracer flow paths. By excavating the test block, the scientists can determine actual tracer movement. This will

with data from field tests conducted in the Calico Hills formation at Busted Butte, scientists can determine how radionuclides might behave at the site. All test data will be available in time to inform a decision on site recommendation and to support a license application, if one is submitted.

Scientific Testing

While new test facilities were under construction, studies continued within the alcoves and niches of the underground Exploratory Studies Facility, and at boreholes and monitoring wells at the surface of the site. Collecting, documenting, processing, and reporting data from site investigations remained a crucial task. To ensure the integrity of rock, soil, and water samples taken from the surface of the site and from underground facilities, staff at the project's Sample Management Facility continued to document each sample's chain of custody and maintain the data in a computerized database.

Core drilling in Exploratory Studies Facility alcove

Maintaining our test facilities received continuing attention. Nearly 8 kilometers (5 miles) of the main loop of the tunnel within the Exploratory Studies Facility and the new 2.8-kilometer (1.67-mile) cross-drift, along with associated alcoves and niches, include numerous basic systems such as utilities, ventilation, communication, potable and wastewater, fire prevention, security, and emergency egress that require periodic maintenance.

Heater tests

Heat generated by radioactive decay of waste will affect the near-field environment and could alter rock mineralogy, mechanical properties, rock and water chemistry, and site hydrology—with consequences for repository system performance. One speculation is that as heat caused moisture 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 such phenomena, DOE's National Laboratories designed three tests that use electric heaters to simulate heat generated by waste. The tests are very different in scale, but they all contribute data toward understanding the effects of thermally driven hydrologic, chemical, and mechanical processes in rocks. Scientists are using 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 block cut out of exposed repository host rock. Heaters were turned on in February 1997 and turned off in March 1998; cool-down was completed in September 1998, as scheduled. Post-heating phase data collection, analyses, and final

Core drilling at the Fran Ridge large block test

reporting will be completed in Fiscal Year 1999.

Preliminary data, particularly those dealing with movement of moisture and condensation within the host rock under controlled thermohydrologic conditions, were used in the total system performance assessment conducted for the viability assessment. These data and the preliminary data from the single-heater test described below were included in a Near-Field Altered Zone Models Report prepared in 1998. A final report will be released in Fiscal Year 1999.

- ***The single-heater test,*** a large-scale underground test, began in August 1996. It employed a single heater approximately 5 meters long to heat a 21 cubic meter (27 cubic yard) volume of rock over a period of 10 months. Instrumentation includes over 300 thermometers that continuously feed data through cables to a computer that records 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. They also provided guidance for planning and construction of the drift-scale test described below. Available information was included in the total system performance assessment conducted for the viability assessment. The test was completed as scheduled in the spring of 1998; the final report will be issued in Fiscal Year 1999.

- ***The drift-scale test,*** many times larger in volume than the single heater test, is the largest such test in the world. In a simulation of an actual waste emplacement tunnel, an underground alcove approximately 48 meters (156 feet) long will be 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. They will heat an estimated 15,000 cubic meters (19,425 cubic yards) of rock to a temperature above 100 degrees Centigrade.

Approximately 3,820 instruments, designed to perform under high temperatures, are positioned within boreholes that were drilled in the walls of the drift and in an adjacent drift. The 147 boreholes total 3,300 meters (2 miles) in length. Gathering data on temperature, humidity, pressure, rock displacement, and other features, these instruments measure how heat flows through the rock, how rock deforms in response to the thermal pulse, and how the chemistry of rock and water change as a result of heating and cooling. At a bank of computers within the test alcove, a sophisticated virtual instrumentation software package runs an automated data acquisition and control system. That system currently receives 5,260 separate data channels, each consisting of one or more wires running from an instrument through cable to the computer bank. The system

Installation of heater cables for drift-scale heater test

Installation of vent line in drift-scale test alcove

Drift-scale test alcove

also determines the frequency of data collection, and it controls the amount of gas delivered to 46 borehole sections for tests that assess changes in pneumatic properties of the rock. This permeability testing measures the degree to which gas can move through rock; changes in gas permeability indicate redistribution of moisture in rock.

Remotely controlled video and infrared cameras monitor the drift-scale test. Working from remote locations, scientists can continuously access this system by telephone to modify system parameters and retrieve data. 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.

Other underground and surface tests

Construction within the main loop of the Exploratory Studies Facility concluded with completion of the seventh test alcove and fourth niche. Within niches and alcoves, multiple boreholes were drilled and instrumented for pneumatic and hydrologic testing. Monitoring and testing also continued within the main loop. Data gathered will advance understanding of how water used in construction affects such factors as capillary pressure and saturation. Designed to provide data on the potential for seepage and the mechanisms by which it could occur, tests within the niches have determined the drift-seepage threshold, a parameter that defines the minimum amount of water that must be present to produce observable dripping in drifts.

The effects of El Niño were studied in two alcoves that were insulated from the drying effects of the ventilation system within the Exploratory Studies Facility. One alcove, several tens of meters beneath the surface, is relatively shallow; one alcove crosses the Ghost Dance Fault and is quite deep. So far, no obvious effects have been detected in either the shallow or the deep alcove.

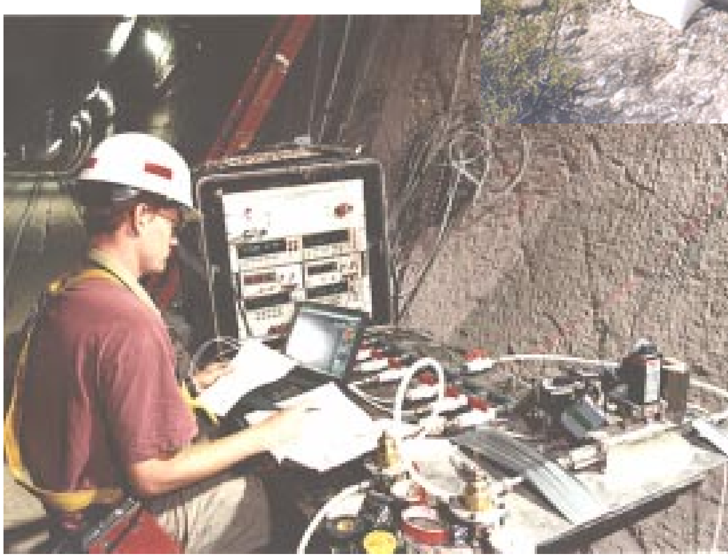
Fracture-matrix interaction and the structural properties of the host rock were also studied in two alcoves; methods included air permeability and air tracer tests, sampling to characterize fracture and matrix for hydrogeologic properties, and geochemical analyses. Results indicate how much water enters the matrix of the rock and how much travels via fractures. Analyses built confidence in characterization of groundwater flow in the unsaturated zone within the repository horizon and beyond.

To understand what could happen if climate change produced heavy rainstorms, an artificial infiltration test was conducted. Between March and August 1998, traced fluid was released through a drip system onto the surface of the site 30 meters (99 feet) above an alcove. Little moisture was detected in the alcove for 2 months; in total, about 3 percent of the tracer fluid was collected. Phase 2 of this test will resume in Fiscal Year 1999.

To determine the cause of the apparent large hydraulic gradient north of the site, a borehole was drilled. Findings indicate that the area of high saturation thought to correspond to the gradient is due to a perched body of water above the regional water table. At the C-Well Complex, tracer tests continued to generate data that help scientists understand water movement in the saturated zone. Those data can be used to test and improve models of radionuclide transport through saturated fractured tuff. To better understand hydraulic and transport parameters and travel times, we prepared to conduct tracer tests in the "Prow

Unsaturated zone transport test at Busted Butte

Moisture migration experiment at Exile Hill (El Niño studies)



Scientist at data terminal work station within drift

Pass," the unit in the saturated zone beneath the repository block that radionuclides transported from the repository would first encounter on entering the water table.

To obtain data on local and regional water table elevations and fluctuations through time, we continued to monitor a network of 22 boreholes. The data collected are used to assess the seasonal transient effects of precipitation and/or evaporation, as well as the effects of local and regional water use, and potential impacts on repository operations.

Laboratory tests

Laboratory testing continued to focus on strengthening our understanding of how heat from waste packages would affect the near-field environment of the engineered barrier system and the potential for transport of radionuclides. These tests are conducted by scientists at DOE's Los Alamos, Lawrence Livermore, and Lawrence Berkeley National Laboratories, and the U.S. Geological Survey. To examine how heat would affect the movement of liquid water and vapor in a repository at the Yucca Mountain site, they used a glass replica of rough fracture planes, as well as fractured rock slabs. Understanding fluid flow through rough fractures, particularly in the presence of heat, allows estimation of the amount of water that could contact waste packages. Preliminary findings of these tests are presented in the 1998 Near Field Altered Zone Models Report. The data collected provided significant preliminary information on the hydrologic, chemical, and mechanical responses of the repository to heat generated by radioactive decay of waste. For example, we learned that when heat causes water to vaporize and the vapor diffuses, this diffusion does not significantly increase the quantity of water flowing away from the heat source.

Studies on radionuclide transport through engineered and natural barriers under controlled laboratory conditions provided data critical to understanding the effects of coupled hydrologic and chemical processes on radionuclide transport under the influence of heat generated by decay of radioactive waste. The experiments on radionuclide solubilities partly filled data gaps on solubilities of neptunium and plutonium, the two radionuclides with the greatest effect on calculations of total radiation dose levels at the accessible environment. The laboratory work also produced preliminary data on transport by natural colloids of plutonium, a relatively immobile radionuclide. As discussed in the sidebar below, the unexpected presence of a minute amount of plutonium in groundwater at the Nevada Test Site indicates the potential for colloidal transport of plutonium and perhaps other radionuclides. The results of these transport studies, including a conservative interpretation of the Nevada Test Site observation and supporting work, were incorporated into the modeling conducted for the viability assessment.

Independent review of our analyses of site data

Detection within the Exploratory Studies Facility of chlorine 36, which may be a product of nuclear testing conducted in the 1950s in the Pacific Proving Grounds and, to a lesser extent, at the nearby Nevada Test Site, had raised questions about groundwater pathways and travel times. An independent peer review of our analysis of these questions and related environmental isotope geochemistry was completed in Fiscal Year 1998. The peer review focused on our sample collection, isotopic analyses, integration of the isotope data with other hydrologic data types, and the resultant interpretation of groundwater travel times and flow pathways through the unsaturated zone. The panel generally agreed with our approach, methodology, and interpretation of data. They recommended enhanced geologic-sampling strategies for isotopic measurements, and closer integration with other groundwater-tracer data and flow-modeling.

Addressing Scientific Controversies

The unprecedented nature of repository siting ensures that scientists will differ over many issues. Within the Yucca Mountain Site Characterization Project, scientists commonly use peer review and expert elicitation to examine and resolve differences. In Fiscal Year 1998, four issues were raised by scientists outside the Project. The nature of those issues, how we addressed them, and their status at the end of the fiscal year are sketched below.

Luther Carter and Thomas Pigford on engineered barriers

An article by Luther Carter, a science writer, and Thomas Pigford, a Professor of Nuclear Engineering at the University of California at Berkeley, in the March/April 1998 *Bulletin of Atomic Scientists* observed that the advantages of the Yucca Mountain site—a dry, sparsely populated environment in a closed hydrologic basin in which water flow is low and water cannot escape—carry a corresponding disadvantage: radionuclides carried away from corroded waste packages by groundwater would form a fairly well-defined plume of contamination, and that plume would not be diluted as much in the dry environment of Yucca Mountain as in a more humid one. Using our preliminary models, they speculated that this plume would begin to threaten the aquifer within 5,000 years, and they recommended a more robust engineered barrier to reduce this threat.

Our models indicate that a contaminated plume approximately 2 kilometers wide could form under the repository footprint and spread to a width of 3 kilometers at a 20-kilometer distance, the presumed location of the nearest population down-gradient of the site. The models indicate that the peak expected annual dose to an average individual during the first 10,000 years is 0.1 millirem. This value is considerably lower than the values cited by the authors, which were based on preliminary models.

To increase assurance that doses will be this low, we are evaluating more robust engineered barriers. Options include drip shields, ceramic coatings, and various types of backfill, including the capillary barrier suggested by Carter and Pigford in their article. Initial design selections will be made in Fiscal Year 1999.

The acceptable dose levels, the location and habits of individuals where compliance would be measured, and the period of time over which compliance must be demonstrated will be determined by the Environmental Protection Agency. As these standards are developed, we will modify repository design to meet them, if necessary.

Jerry Szymanski on repository flooding

The Nuclear Waste Technical Review Board released its review on July 24, 1998, of 11 new reports submitted in January 1997 by Jerry Szymanski, a former DOE scientist, asserting that ongoing, intermittent hydrothermal activity and large earthquake-induced changes have caused the water table at Yucca Mountain to rise periodically hundreds of meters from deep within the earth's crust. With the help of outside consultants, the Board concluded that a credible case for such upwelling has not been made and that research to further evaluate this hypothesis should have a lower priority than more important issues.

Overall, the Board concluded that the material submitted to them does not significantly affect the conclusions reached by a 17-member panel in a 1992 National Academy of Sciences report. That panel had concluded from observations in the field and from geochemical data that there is no evidence to support Szymanski's theory.

The Board also stated that additional research on these issues should have a lower priority than research on more important issues related to repository performance. However, the Board believes that determining the ages of fluid inclusions (small amounts of liquid and gas trapped in tiny cavities in mineral deposits) would help resolve this issue. The Board suggested that Federal and State of Nevada scientists undertake a joint program to collect, date, and analyze fluid inclusions, to help eliminate some past disagreements associated with sample collection and handling. We agreed with the Board's recommendation and communicated our interest in such a program to the State of Nevada on September 3, 1998.

Brian Wernicke, et al., on horizontal ground expansion of the site

One way that scientists determine the stability of the Yucca Mountain site is to measure the rate at which the distance between any two points on the surface of the site changes. Distances between thirteen permanent markers (or monuments) at the site are periodically surveyed to make this determination.

In an article in the March 27, 1998, issue of Science magazine, Brian Wernicke, an earth scientist at the California Institute of Technology, and eight co-authors reported that geodetic measurements they had made at the Yucca Mountain site indicate a relatively high strain rate: a N65^{E}W extension rate of 50±9 nanostrain/year (1.7 ± 0.3 millimeters/year over a 34-kilometer baseline). In response, the U.S. Geological Survey (USGS) conducted a resurvey during the summer of 1998 of the Project's 13-station, 50-kilometer aperture, geodetic array centered on the site. The results indicate an extension rate an order of magnitude lower (5±12 nanostrain/year, 0.25 ± .6 millimeters/year) than the rate claimed by Wernicke et al. The USGS results are based on data spanning 1983-1998 and are corrected for coseismic deformation of portions of the geodetic array associated with the Little Skull Mountain earthquake in June 1992. The study by Wernicke et al. only included data for 1991-1997 from a six-station network without corrections for the coseismic effects of the Little Skull Mountain earthquake.

In the view of project scientists, all of these factors render the result reported by Wernicke et al. questionable. The USGS presented the results of the resurvey at the Annual Fall Meeting of the American Geophysical Union in San Francisco, December 6-10, 1998. Under a cooperative agreement between the Department and the University and Community College System of Nevada, researchers are collecting geodetic measurements to more accurately determine the strain rate of the earth's crust in the Yucca Mountain region. The results should resolve questions about the rate of horizontal ground expansion, and they may also further understanding of the rate at which earthquakes occur in the Yucca Mountain region.

Plutonium in groundwater at the Nevada Test Site

At the Nevada Test Site, a minute amount of plutonium generated by nuclear testing was detected in the groundwater approximately 1 kilometer from the location of a nuclear test. Plutonium is generally considered to be practically untransportable by groundwater due to its very low solubility and high potential for sorbing to rocks. An interim interpretation is that plutonium is transported via colloids, very fine particles suspended in groundwater. If the transport observed at the Nevada Test Site is indeed due to plutonium's sorption onto the colloids that naturally occur in the groundwater, our radionuclide transport model and total system performance assessment need to include colloidal transport of plutonium.

The Nevada Test Site is working to determine the mechanism for this transport of plutonium. We are conducting laboratory and modeling work on colloids and plan to use data from the Test Site and from DOE's Hanford Site and Idaho National Engineering and Environmental Laboratory to validate our colloid models. Preliminary models of colloidal transport of plutonium were included in the total system performance assessment conducted for the viability assessment.

The Probabilistic Seismic Hazard Analyses Final Report was completed in September 1998. It is the product of an expert elicitation process involving twenty-five earth scientists from academia, industry, and government. The hazard analyses were based on evaluations of seismic source characteristics, earthquake ground motions, and fault displacement that reflect interpretations of different scientific hypotheses and models using all relevant data from within and outside our Program. The results form the basis for developing seismic design inputs for a repository at Yucca Mountain, and they support an assessment of its long-term performance.

Confirmation of site model through direct observations

Data from site investigations are 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.

The model represents geologic features within a 160-cubic-mile area, to a depth of 13,000 feet, as interpreted from data taken from 60 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 our hydrologic studies.

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 model continues to improve as we incorporate new data into it.

Interdepartmental collaboration

In Fiscal Year 1998, we began to integrate our radionuclide transport modeling effort with similar efforts at DOE Environmental Restoration Program sites, including the Idaho National Engineering and Environmental Laboratory, the Hanford Site in Washington State, and the Nevada Test Site. The U.S. Geological Survey is also participating in this effort. We plan to use these DOE sites as analogs for transport modeling, including transport of plutonium by colloids. In turn, those sites could benefit from using the modeling methodologies we develop. The results will help build confidence in the transport models we use in the total system performance assessment that will inform a decision on site recommendation.

We continued to collaborate with the Nevada Test Site on a major project to combine our databases to develop a comprehensive regional hydrologic model. This model will incorporate the best features of two independently produced models. The Test Site's model was developed to study existing contamination, and 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. In Fiscal Year 1998, collaboration proceeded on several fronts, including field work to gather new data, refinement of the regional hydrogeologic framework model, and incorporation of new data into the model. This 5-year effort will yield a more comprehensive model offering greater calibration and steady state and transient simulations.

Design and Engineering

Design as an evolving process

Throughout repository development, new information—from confirmatory testing, scientific and technological advances, operational and cost considerations, the demands of the licensing process, or other sources—would continue to arise. Accordingly, we are designing the engineered barriers of the repository system to be flexible enough to accommodate changes warranted by new information and to permit consideration of alternative engineered components and design options that could enhance confidence in overall performance. Because we will continue to identify and evaluate different combinations of components and design options to determine their potential contribution to overall performance, design may evolve even after the repository has been licensed.

In Fiscal Year 1998, design work focused on producing Volume 2 of the viability assessment, "Preliminary Design Concept for the Repository and Waste Package." Documentation of reference designs for repository surface and subsurface facilities, the waste package, and other engineered barriers served as the basis for Volume 3, total system performance assessment, and for the cost estimates in Volume 5. Designers also contributed to documentation that will support development of the environmental impact statement.

As design evolves, the reference design for the viability assessment will be superseded by a next-generation reference design that will support a decision on site recommendation and a possible license application. Fiscal Year 1998 therefore also saw a narrowing focus on shorter-term engineering cost-benefit and trade-off studies and analyses that can resolve technical issues that affect selection of the next reference design. Toward this end, a major initiative was planning for the evaluation in Fiscal Year 1999 of design alternatives. Evolution of design decisions was documented through methodical review of past work. Designers worked with regulatory and licensing staff to define the level of design detail appropriate to support decisions on site recommendation and a license application. A Repository Consulting Board under contract to our management and operating contractor continued to review our design work and advise us.

Selecting and documenting repository designs

For design of repository surface facilities, we evaluated the site-wide systems and facilities and nuclear facilities needed to support the North Portal operations, where waste would be received, including gas/liquid systems; communications and control systems; the electrical system; safety and security systems; logistics and administrative systems; support systems for the Waste Handling Building, Waste Treatment Building, and Carrier Preparation Building; and the North Portal site layout. An integrated waste-handling simulation model was developed to assess the throughput capabilities of the repository from receipt at the gate to emplacement in the drift. We also developed the design basis to support a decision on site recommendation and possible license application. Systems evaluated included the Secondary Waste Treatment System, Carrier/Cask Handling System, Assembly Transfer System, Disposal Container Handling System, Cask/Canister Cool-down System, Assembly Drying System, and Waste Package Remediation System.

Work was initiated to evaluate specific aspects of design, including radiological design (dose assessment, criticality, and shield-wall analyses); architectural space programming; heating, ventilation, and air conditioning for the Waste Handling Building; process design (secondary waste treatment, decontamination systems, and secondary low-level waste generation rates); test requirements for development of waste handling equipment; and an operations staffing report.

Subsurface facility design documentation consists of drawings and specifications for structures, systems, and components of the repository system, supported by analyses and trade-off studies.

Subsurface structures for which documentation was developed included the ventilation shafts, access ramps, access tunnels, and emplacement drifts. Systems include ground support, ventilation, fire protection, data gathering and monitoring, communications, and systems that will support performance-confirmation monitoring. Major components included the waste transporter and the emplacement gantry crane.

Technical documentation developed for the engineered barrier system included the following:

- System design descriptions. To support a license application, technical documentation is being prepared for each of 60 major systems in a Monitored Geologic Repository. Each system design description specifies applicable regulatory, performance, and operations and maintenance requirements, and describes the system design, technical basis for the design, design analyses, design limitations, interface with other systems, and casualty events and means of recovery. The 30 descriptions issued in Fiscal Year 1998 supported the viability assessment; 20 more are planned for Fiscal Year 1999. All will be revised as design evolves.
- Monitored Geologic Repository Concept of Operations. This document provides an integrated, conceptual description of the Monitored Geologic Repository system and its operations. By documenting decisions on design concepts, it facilitates a common understanding of system operations among planners, developers, and implementers.

DOE spent nuclear fuel: managing heterogeneity

DOE manages over 250 kinds of spent nuclear fuel, and their physical, chemical, and nuclear characteristics vary considerably. To reduce the physical complexity posed by this heterogeneity, we worked with the Office of Environmental Management's National Spent Nuclear Fuel Program to develop specifications for the dimensions of a suite of standardized canisters that can accommodate all types of spent nuclear fuel. DOE sites can use these specifications to design and fabricate the canisters they would need to ship DOE and naval spent nuclear fuel to a repository. Providing DOE sites with this guidance equips them to prepare more efficiently for near-term storage and eventual shipping, and it ensures a compatible interface with repository operations. At a repository, standardization would simplify waste receipt and handling, thus reducing the potential for worker exposure to radiation and reducing operating costs.

To reduce the analytic complexity posed by the heterogeneity of DOE spent nuclear fuel, we defined categories to bound these waste forms. The categories streamline our analyses of criticality and total system performance assessment. They would also reduce the complexity of the safety analysis report we would submit to the NRC in a licensing proceeding, and they would simplify the NRC's review of our license application. Employing categories also simplifies data collection for the generators and custodians of DOE spent nuclear fuel.

We also defined categories of DOE spent nuclear fuel for the purpose of designing the repository's surface and subsurface facilities and operations. Using categories will simplify the integrated safety assessment of waste handling operations at a repository. That assessment would be part of a preclosure safety case made in a licensing proceeding.

Modifying policy on repository closure

NRC regulations stipulate that a repository must be kept open for at least 50 years after the start of waste emplacement. In Fiscal Year 1998, we modified our policy to allow future decision makers greater latitude in determining when to close the repository, so that if they want to increase confidence in performance through extended monitoring, they can. The repository could still be closed as early as 50 years after the start of waste emplacement, but repository design would not preclude its being kept open for at least 100 years, and with a reasonable expectation of appropriate maintenance, for up to 300 years. Consistent with this change, the name of the repository system was changed from *Mined Geologic Disposal System* to *Monitored Geologic Repository.*

Planning for performance confirmation monitoring

Planning for performance confirmation monitoring continued. It requires establishing the baseline for current conditions against which repository performance would be compared, defining the tests and related activities necessary to monitor performance, and designing subsurface facilities to include necessary instrumentation for monitoring. Factors to be monitored 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.

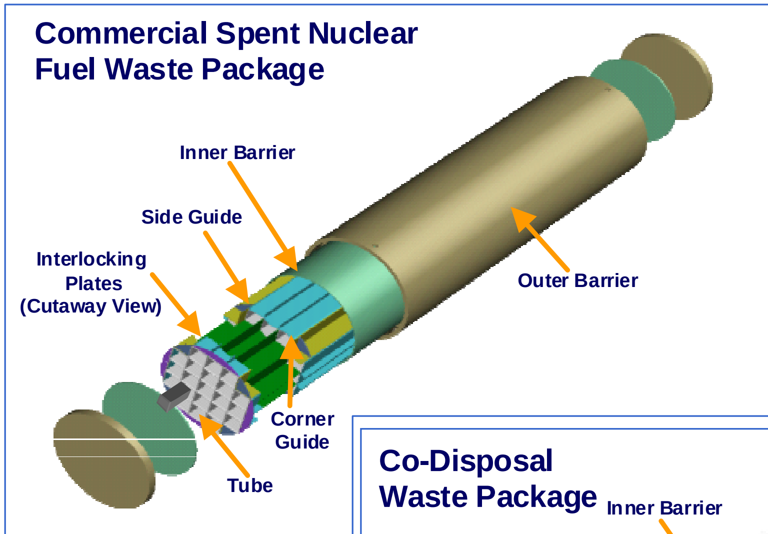
Waste package design

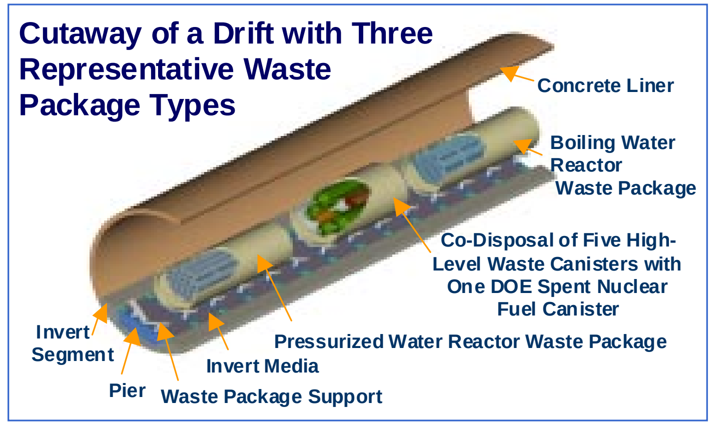
We are relying on a defense-in-depth strategy to isolate radionuclides and retard their transport: multiple engineered barriers coupled with natural barriers, both physical and chemical, will work in concert. A principal engineered barrier will be the waste package. Because of the heterogeneity among waste forms, suites of waste package designs are being developed to more economically accommodate all waste forms. For example, different waste forms may require different levels of heat transfer capability and control of criticality, a spontaneous nuclear reaction that would release tremendous energy. If a single, most conservative, design were relied on for all waste forms, costs would be unnecessarily high. While the designs differ in diameters, lengths, and criticality safety measures required, the primary feature of the waste package designs—the thickness of the inner and outer barrier walls—remains the same for all the designs.

In Fiscal Year 1998, we completed reference waste package designs for the viability assessment for all waste forms in the program baseline: commercial spent nuclear fuel in the form of bare assemblies and in canisters, naval spent nuclear fuel, glass high-level waste, immobilized plutonium, mixed-oxide (MOX) spent nuclear fuel, foreign and domestic research reactor fuel, and spent DOE production reactor fuel. These designs were subjected to thermal, structural, shielding, and criticality analyses to demonstrate compliance with existing design requirements. All analyses were coordinated with other repository design work to evaluate handling concepts and underground emplacement strategies.

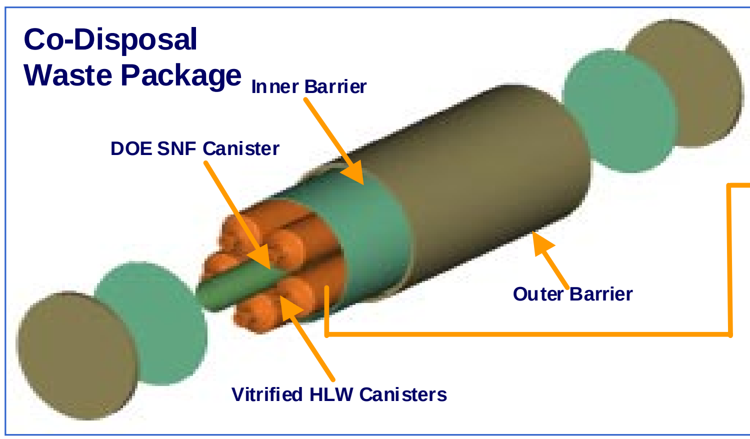
Included in criticality analyses was the co-disposal concept for high-level radioactive waste and key types of DOE spent nuclear fuel. The concept entails placing a canister of DOE spent nuclear fuel into the center cavity of a disposal container that holds five canisters of high-level radioactive waste. This configuration would minimize the number of disposal containers required, and thus their total cost, while satisfying requirements for criticality control.

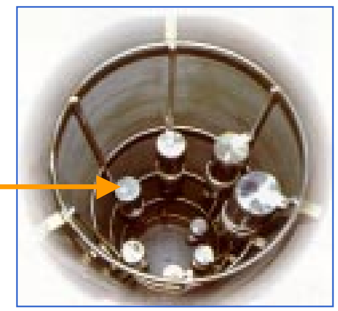
A peer review of work conducted to develop ceramic coatings on the outer surface of the waste package was completed. The peer review concentrated on the principles governing the use of ceramic coatings for corrosion protection and on the models developed to predict the performance of waste packages with ceramic coatings. The reviewers identified mechanical and chemical processes that need to be understood and incorporated into the model. They





Waste packages contain canisters of defense high-level waste, commercial spent nuclear fuel, and immobilized plutonium waste form.





Ceramic mixture of plutonium oxide "discs" embedded in canisters which will be filled with vitrified high-level radioactive waste. The canisters will meet the spent fuel standard to prevent diversion.

Waste package designs

recommended that we consider ceramic coating materials and coating application processes other than those considered to date and that a broader set of degradation mechanisms support the modeling effort. We are taking their recommendations into account.

Development of fabrication techniques also continued. A mockup of the carbon steel/alloy-22 waste package was successfully fabricated. The dimensions of this mockup were roughly the full diameter of a waste package and one-quarter its length. Lids for both barriers were welded and inspected with nondestructive examination techniques. Laboratory testing of candidate waste package materials is described below.

A new methodology for calculating criticality safety

Although the likelihood of criticality would be extremely remote in a repository, NRC licensing regulations require that in a licensing proceeding criticality safety be demonstrated. Because criticality safety has never before been demonstrated on the scale demanded by a repository, a methodology must be established that is acceptable to the NRC. We completed the Disposal Criticality Analysis Methodology Topical Report in Fiscal Year 1998 and will submit it to the NRC in Fiscal Year 1999. The report, and referenced material, explain how waste packages will be evaluated to demonstrate criticality safety. The methodology presents arguments for taking burnup credit for commercial spent nuclear fuel types with very high initial enrichments and/or burnup values. A unique feature of the methodology is that it employs a probabilistic rather than deterministic approach to safety assessment.

Support for design and performance assessment

The work described below supported design and total system performance assessment for the viability assessment. The testing and modeling are being continued, to support the decision on site recommendation, a possible license application, and performance confirmation.

- *Waste form.* Information on waste form characteristics was updated for the viability assessment. Long-term tests on commercial spent nuclear fuel and vitrified high-level waste continued. A more rigorous program to investigate the condition of commercial spent nuclear fuel cladding after storage, and its degradation thereafter, was initiated. Studies of colloids and secondary-phase phenomena were pursued. Secondary phases, solid deposits created on the surface of the waste form as a result of degradation, are significant because they contain some material from the original waste form and can inhibit further corrosion. Waste form testing and modeling were performed at DOE's Pacific Northwest, Lawrence Livermore, and Argonne National Laboratories.
- *Waste package materials.* Information on the characteristics of engineered materials was updated for the viability assessment. Long-term tests continued on corrosion allowance materials, corrosion-resistant materials, and ceramics. Shorter-term tests focused on galvanic protection, crevice corrosion, stress corrosion cracking, and microbiologically influenced corrosion. The results of total system performance assessment modeling led us to change the selection of a waste package material for the inner barrier of the waste package, from one nickel-based alloy to another that resists corrosion better but is no more expensive. Waste package material testing and modeling were performed at Lawrence Livermore National Laboratory.

Evaluating alternative design concepts

In the viability assessment, we committed to reviewing a diverse set of design alternatives in order to select a design for site recommendation and licensing that maximizes repository performance and is licensable and cost-effective. Toward that selection, we began planning to structure and staff an evaluation of major design alternatives. Such evaluation is required by current 10 CFR 60, and it has been recommended by the Nuclear Waste Technical Review Board. The design will be selected in 1999.

In evaluating alternatives, we are taking into account the positions and views of oversight and stakeholder groups, the total system performance assessment Peer Review Panel, and our Repository Consulting Board. The work plan we developed in Fiscal Year 1998 requires us to establish a decision analysis methodology, develop evaluation characteristics and selection criteria for design features and alternatives, evaluate design features to understand the potential for improving repository performance, evaluate and incorporate performance-enhancement design features into alternative design concepts, evaluate enhanced design alternatives to identify those that best meet the evaluation criteria, and prepare a defensibly documented report that identifies the preferred reference design.

The design features and alternatives will be evaluated against the following criteria: (1) postclosure performance, (2) preclosure performance, (3) assurance of safety (defense-in-depth), (4) engineering considerations of simplicity and precedent, (5) operations and maintenance, (6) cost and schedule impacts, (7) flexibility, and (8) environmental impacts.

We have defined an initial set of eight design alternatives and twenty-six design features and where appropriate will use performance assessment models to assess their impacts on repository system performance. We will first rank each option by performance, keeping in mind the limitations inherent in some aspects of the performance modeling. Then we will combine options that are most effective into several enhanced design alternatives that can be examined using probabilistic modeling. Some model enhancements will be needed to support this effort.

Quality Assurance

Over the past 2 years, we have worked to consolidate responsibility for all quality assurance (QA) oversight functions into a single organizational unit under the Office of Quality Assurance. This effort was completed in Fiscal Year 1998, when the Office assumed the

On-site quality control inspections

responsibility for performing all quality control inspections required to support site characterization. This function had previously been performed by a management and operating subcontractor. Consolidation resulted in annual savings of approximately $4 million, enhanced the independence of QA personnel, and provided greater consistency in the interpretation of QA requirements.

The Office of Quality Assurance met its annual goal of providing QA audit and surveillance coverage for the full scope of quality-affecting activities performed by OCRWM, OCRWM's contractors, and organizations within the Office of Environmental Management that interface with OCRWM. Audit and surveillance schedules, as well as the completed audit and surveillance reports, have been posted on the OCRWM Web site for reference by OCRWM personnel and external stakeholders. QA audits and surveillance resulted in identification of issues related to data that could be used to support the Secretary's decision on site recommendation. Corrective actions are being aggressively implemented to ensure a quality pedigree for data that support scientific and technical conclusions.

Ensuring that total system performance assessment efforts achieve full compliance with QA requirements received close attention; QA personnel worked with technical organizations to evaluate and enhance process controls for performance assessment model development and validation. Greater traceability and transparency in this work will help build confidence in the total system performance assessments that will support a decision on site recommendation and, potentially, a license application.

We continued to work on QA matters with the Office of Nuclear Energy's Naval Nuclear Propulsion Program and with the Office of Environmental Management's High Level Waste Program and National Spent Nuclear Fuel Program. We also initiated formal interactions with the Office of Fissile Material Disposition. Because these organizations are responsible for waste forms destined for a geologic repository, we want to ensure that they apply appropriate QA requirements to activities that could impact our acceptance and disposal of their materials.

External Oversight

Interactions with the NRC

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 the site recommendation is accepted by the President and Congress, the Commission must then review and issue a final decision approving or disapproving our application for construction authorization within 3 years. The license application we submit would be a lengthy, complex technical and regulatory document, supported by what is expected to be an unprecedented volume of technical information.

If our work is to satisfy the Commission, and if the Commission's comments and review are to be effective, we must share a common understanding of issues important to repository performance, appropriate methodologies for assessing them, what associated licensing requirements should be, and what information should be available for the initial license application. Accordingly, for many years we have been conferring with the NRC on these matters.

In the near term, the viability assessment provides a valuable frame of reference for our prelicensing interactions because it addresses issues essential to licensing. And the Commission's views on the approach to licensing set forth in the viability assessment will be important to policy makers' decisions about the Program. In Fiscal Year 1998, we held quarterly technical meetings and one management meeting with the NRC to keep them informed of our overall progress and to ensure that issues that need management attention are being dealt with. As we move closer to potential licensing, QA issues are becoming more visible; we held two meetings on this topic. We have plans in place to resolve outstanding QA concerns, and the NRC is closely monitoring our progress.

We also met with the NRC twice on development of the viability assessment, twice on total system performance assessment methodologies and results, and twice on our plans for a license application. These interactions kept the NRC abreast of information we were incorporating into the viability assessment and permitted us to hear and take into account NRC concerns before the viability assessment was completed. In turn, the NRC has released initial or revised progress reports on the status of efforts to resolve the key technical issues that the Commission thinks must be addressed for licensing. Our license application plan and the NRC's issue resolution status reports will form the basis for future discussions on the work necessary for licensing.

For some years, the NRC and the Department have been planning for an electronic licensing support system that would meet the Commission's requirement for electronic access to the unprecedented volume of documents that would support a repository licensing proceeding. Requirements for this system are governed by NRC rules. The system was first conceived as a stand-alone computer system to be built by DOE and certified by the NRC to contain all information relevant to licensing, but since those plans were formulated, information technology has advanced dramatically. In November 1997, the Commission published a draft rule proposing to move to electronic filing of documents and the use of an Internet-based network that would enable all parties to repository licensing to share and access information through the Internet. We expressed our agreement with the NRC proposal in our comments on the rule. The NRC published its rule in final form in December 1998. In keeping with our commitment to this method of sharing information, we posted the viability assessment and supporting documents on our Web site the same day they were delivered to Congress and the President.

Interactions with the Nuclear Waste Technical Review Board

Created by Congress to oversee the technical and scientific aspects of our work, 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 1998, the Board released its *Report to the U.S. Congress and the Secretary of Energy: 1997 Findings and Recommendations.* The Board stressed the importance of fully evaluating alternatives to the reference design for a repository before selecting a design for licensing. The Board also recommended that we evaluate variations in potential doses from a repository for groups with different locations, ages (particularly children), and lifestyles. They further recommended that we consider the need for site-specific, rather than generic, data to support models of the biosphere, particularly for how radionuclides might move from soil into plants. Finally, the Board suggested that we make full and effective use of expert elicitations to address the inherent uncertainty in scientific understanding and to make assessments before all relevant data can be collected.

In our formal response, we reported that we had established an internal working group to identify and evaluate major design alternatives in order to develop the repository design that will support the Secretary's decision on site recommendation and a license application. Concerning potential doses to children, we said that currently available information is not sufficient to fully address agedependent differences, but that we will conduct a preliminary evaluation of the potential impact on children and present the results in a technical report. We also stated that we are evaluating whether the use of generic data on soil-to-plant transfer of radionuclides is an important source of uncertainty in our biosphere models. We agreed with the Board on the value of expert elicitations and stated that we are taking into account the Board's suggestions on how to treat the results.

In December 1997, the Board submitted a letter report to Congress and the Secretary. In addition to recommending that we consider alternative designs, the Board stressed the importance of a robust engineered barrier to reduce uncertainties in overall repository performance. The Board pointed out the importance of convincing the scientific community that our conclusions are based on well-founded models and appropriate data. The Board also noted the importance of obtaining hydrologic data from the cross-drift. We agreed with these recommendations and have been addressing them in our ongoing site investigation, design, and performance assessment work.

The Board's review of Jerry Syzmanski's reports on possible future upwelling of water into a repository at Yucca Mountain is discussed in the sidebar above on scientific controversies.

In Fiscal Year 1998, the Full Board held three meetings; six panel meetings were held on repository radiological standards, transportation, waste characteristics, performance assessment, and waste package design. The Board began a process of providing us with early feedback from its meetings through written preliminary comments; in Fiscal Year 1998, the Board sent us three letters with preliminary comments. We found this process valuable and responded in writing to each of these letters to ensure that important issues are addressed in a timely manner.

Site Characterization Progress Reporting

The Nuclear Waste Policy Act requires OCRWM to submit to the Governor and legislature of the State of Nevada and to the NRC semiannual site characterization progress reports. The 16th report was issued in October 1997. The 17th report, issued in April 1998, streamlined the format of past reports. The 18th report, issued in July 1998, took the form of a letter report, as OCRWM wanted to conserve its resources for development of the viability assessment.

Relations with Affected Parties and the Public

Under the terms of the Nuclear Waste Policy Act, the State of Nevada, Nye County (the county within which the Yucca Mountain site is located), and nine counties contiguous to Nye County (including Inyo County in California) are entitled to exercise oversight of our site characterization activities and to receive financial assistance for this purpose. The Act 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 1998.

In Fiscal Years 1996 and 1997, Congress did not provide funds for the State of Nevada and the ten affected counties to conduct oversight of our work. In Fiscal Year 1998, Congress provided $5 million to the affected counties and no funds to the State of Nevada. With reinstatement of oversight funding, those counties previously forced to close their oversight offices reopened them, and all ten affected counties became more active in their oversight. The State of Nevada continued to operate its Nuclear Waste Project Office using unspent funds carried over from previous years, supplemented by limited appropriations from the State legislature.

In Fiscal Year 1998, we continued formal and informal interactions with the ten affected counties and the State. Project staff hosted two meetings in Las Vegas with their representatives, provided project updates to the County Commissions, Boards of Supervisors, and State and local government committees, and conducted 18 site tours for county and State officials. We also continued to provide used, surplus computers to the school districts within the affected counties, distributing 150 systems and a variety of associated computer peripherals.

Nye County drilling program. Nye County invited OCRWM to participate in planning for the County's Fiscal Year 1999 initiative to drill boreholes near Amargosa Valley in the saturated zone in which radionuclide transport could occur. For us, sampling and data collection will yield needed information about water flow and fault structure in the saturated zone. The County is designing the boreholes for use in an early warning system that would be part of performance confirmation monitoring if a repository is developed at the site. OCRWM will provide funding for the drilling program under a cooperative agreement with the County.

Payments-Equal-to-Taxes (PETT). OCRWM continued funding its PETT agreements 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 $6.98 million was provided in Fiscal Year 1998, of which $6.3 million went to Nye County.

Cooperative agreement with the University and Community College System of Nevada. The Department executed a 5-year cooperative agreement with the University and Community College System of Nevada for independent and objective scientific and engineering studies relevant to site characterization and the potential for Yucca Mountain's use as a repository for high-level radioactive waste. The agreement could provide up to $40 million to the University and Community College System. This marks a departure from the past practice of direct congressional appropriations to the University system. The agreement envisions collaboration among independent university and college researchers and Yucca Mountain Site Characterization Project scientists and engineers. Such collaboration would stimulate pursuit of scientific disciplines in Nevada, enhance workforce diversity, ensure the availability of critical skills needed to support current and future OCRWM missions, and foster new thinking regarding those missions. Tasks pursued under this agreement are described elsewhere in this report.

Outreach to the public

We continued our efforts to provide timely and accurate information about the Yucca Mountain Site Characterization Project through a cost-effective communication program that reached stakeholders, interested groups, and members of the public through a variety of means: print and electronic media, including our Web site, newsletters, and fact sheets; a toll-free information number; science centers; and correspondence. We also promoted two-way communication with technical and nontechnical audiences through our Yucca Mountain Speaker's Bureau, tour program, exhibits at key events, and meetings. We produced three videos to inform the public of our progress.

In 1998, we conducted more than 250 tours of the Yucca Mountain site, briefing more than 4,600 visitors. Through the speaker's bureau, we conducted 153 presentations to schools and civic, business, and professional groups, reaching more than 10,650 people within Nevada. We answered more than 1,600 phone calls and letters, providing written responses and project literature. We also filled more than 2,200 requests for project-related documents, shipping more than 20,100 documents.

Yucca Mountain exhibit

Our Web site was heavily visited by members of the public, students and teachers, businesses, and government entities around the world.

In partnership with the Harry Reid Center for Environmental Studies at the University of Nevada, Las Vegas, we continued to develop a CD-ROM-based "virtual" tour of Yucca Mountain for people who are unable to tour the site in person.

We provided expanded educational opportunities to almost 30,000 Nevada students in kindergarten through twelfth grade, as well as more than 300 Nevada teachers and parents, through such activities as 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.

The Environmental Impact Statement

The Nuclear Waste Policy Act requires the Secretary to include an environmental impact statement (EIS) as part of a site recommendation, and that statement will assist the Secretary in making a decision on whether to recommend the site. A major work product, the EIS will evaluate the effects of constructing, operating and monitoring, and closing a repository at the Yucca Mountain site, and the impacts of transporting commercial and DOE-managed spent nuclear fuel and high-level radioactive waste to the site under various scenarios involving both truck and rail transport.

To evaluate these impacts it is necessary to make assumptions about the quantity of waste to be emplaced in a repository. Under the Nuclear Waste Policy Act, no more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste may be emplaced in a first repository until a second is in operation. The EIS will evaluate the impacts of a 70,000-MTHM inventory. In Fiscal Year 1998, to reflect the evolution of program policy and design and as a result of what we learned through EIS scoping, we decided that the EIS should also evaluate the impacts of disposing of the entire projected inventory of nuclear materials destined for geologic disposal, a quantity that substantially exceeds 70,000 MTHM. Current OCRWM policy, documented in the Civilian Radioactive Waste Management System Requirements Document, Revision 5, is that repository design accommodate the total quantity of materials projected to require disposal. Design and total system performance assessment analyses of this inventory enable us to evaluate the physical capability of a repository at the Yucca

Mountain site to safely isolate all these wastes. These analyses could support a future decision by Congress on the need for a second repository. At the time of actual waste emplacement, OCRWM would comply with any statutory, regulatory, or license limitations in effect.

The EIS will also examine the impacts of a "no action" alternative in which 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE-managed nuclear materials would remain in on-site storage. The storage sites would be commercial nuclear power plant sites and DOE's Hanford Site in Washington State, the Idaho National Engineering and Environmental Laboratory, the Savannah River Site in South Carolina, the West Valley Site in New York State, and Fort St. Vrain in Colorado.

We engaged an independent contractor to perform impact analyses and help us write the EIS. Because ongoing work and modeling improvements must be reflected in the draft and final EIS as they are being developed, we worked to ensure consistency between the EIS and the viability assessment and other program and DOE documents where appropriate.

A DOE Management Council continued to help guide development of the EIS and ensure coordination within the Department. The Council includes representatives of the Office of Environmental Management with responsibility for DOE-managed nuclear materials, and representatives of the Office of the General Counsel and the Office of Environment, Safety and Health. Internal DOE management council meetings on the EIS continued. We briefed affected units of government on the process, stipulated by the National Environmental Policy Act and modified by the Nuclear Waste Policy Act, for developing the EIS and on our schedule. We also made presentations on analyses we were conducting for the EIS to the Nuclear Waste Technical Review Board.

As the fiscal year closed, preliminary chapters were being drafted by the independent contractor and submitted for OCRWM review. The draft EIS is scheduled to be issued in 1999 for comment by the public and governmental agencies; a final EIS is scheduled for publication in Fiscal Year 2000.

Worker Safety

A superior safety record

Safety precautions are integrated into all work performed by the Yucca Mountain Site Characterization Project. Worker training and line management accountability are critical to success in meeting this goal. The Project's safety and health program requires that written safety plans and procedures be prepared before work begins and that they be followed as work progresses. Active oversight is exercised through assessments, surveillance, and inspections performed by OCRWM and its contractors, with technical support from other Federal agencies and independent technical experts.

During the course of Fiscal Year 1998, construction was under way at multiple locations at the site: the cross-drift, the Busted Butte test facility, alcoves and niches within the Exploratory Studies Facility, and at surface borehole-drilling locations. No serious injuries directly related to excavation operations occurred. The Yucca Mountain Site Characterization Project's annual rates of safety- and health-related incidents and illnesses remained well below those of commercial enterprises in similar industries on a national scale, as well as below DOE-wide rates. The 5-year total recordable injury and illness rate was approximately 60 percent below the comparable industry rate. The 5-year lost workday incident rate, based on time lost due to injury, was about 52 percent below comparable industry rates.
The 5-year safety and health cost index was approximately 40 percent better than the DOE complex-wide average.

Implementation of a departmental safety initiative

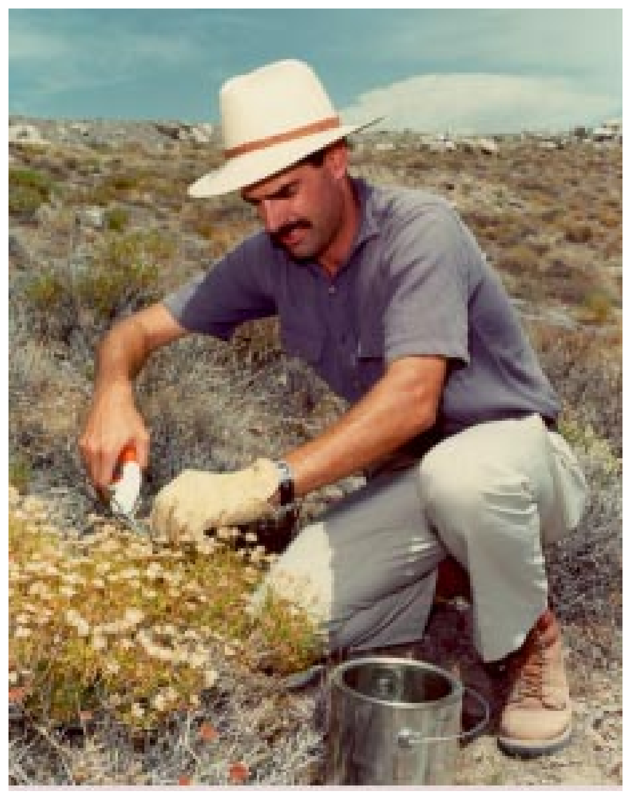
While OCRWM has enjoyed an outstanding safety record, maintaining that record demands continued daily attention, and the goal of continuous improvement demands continued effort. In Fiscal Year 1998, we began to implement a departmental requirement for a comprehensive, integrated safety management system. The goal is to systematically integrate environmental, safety, and health considerations into management and work practices at all levels. To institutionalize the practice of integrating safety into every task, the system centers on a rigorous process: (1) defining the scope of work, (2) analyzing hazards, (3) designing and implementing hazard control, (4) performing the work, and (5) seeking continuous improvement through feedback. Responsibility for safety rests not only with line management, but with individual employees, who are responsible both for their own safety and for that of their co-workers. The requirement for this system applies to all OCRWM and contractor and subcontractor personnel.

In July 1998, we issued a manual that defines the functions, responsibilities, and authorities of OCRWM personnel under this system. We also modified the contract with our management and operating contractor to require that it implement this system, and we provided guidance for development of its implementation plan.

Early in Fiscal Year 1999, the Department sponsored a workshop on this safety initiative to help employees from across the complex learn from each other. We attended, and will continue to consult with other sites to learn from their experience how we can best tailor the system to the Yucca Mountain Site Characterization Project, which is engaged in both scientific investigations and the construction of test facilities.

Environmental Protection

OCRWM is committed to performing its work at the Yucca Mountain site in a manner that minimizes adverse environmental impacts. To accomplish this, at the start of site characterization we implemented an environmental protection program entailing extensive monitoring and mitigation. The program covers a wide range of activities and ensures that all structures are built, operated, and managed in a manner that will protect, maintain, and restore environmental quality; minimize potential threats to the environment and the public; and comply with environmental regulations and DOE policies. In Fiscal Year 1998, this program continued to function smoothly.



Biologist collecting plant samples on Yucca Crest

Data collection and monitoring

To assess the effects of site characterization and to identify any future possible effects of repository construction and operation, we continued to monitor air quality, meteorology, water quality, terrestrial ecosystems, and cultural resources (archaeological and Native American). We also monitored to determine existing background levels of radiation. This information equips us to mitigate any impacts before they become significant. To date, no significant adverse environmental impacts have been detected. Data collection supported repository design, biosphere modeling, total system performance assessment, and the viability assessment. It also contributed to preparation of information that will support the Secretary's decision on site recommendation, and a license application, if the site is recommended.

Surveys and reclamation

Before the start of proposed surface-disturbing activities, we conducted surveys to inventory and protect ecological and cultural resources. Specially trained personnel thoroughly examined the areas in question in advance of proposed activities for the presence of important plant and animal species (for example, the threatened desert tortoise, *Gopherus agassizii*) and items of archaeological significance (primarily Native American artifacts at Yucca Mountain). Reclamation plans were developed for each disturbed site to allow restoration following completion of an activity. Our habitat reclamation program continued to develop the most effective techniques for reclaiming disturbed areas in the harsh desert environment. Final reclamation was initiated at 36 sites totaling 1.95 hectares (4.78 acres).

Environmental compliance

To maintain complete environmental compliance, we continued to review, analyze, and interpret applicable Federal and State environmental laws, regulations, and codes while developing and implementing strategies, plans, and procedures to satisfy environmental compliance requirements. The most fundamental function of the environmental program, since the earliest days of the Project, has been the acquisition and subsequent renewal, when required, of permits necessary to conduct site characterization activities at the Yucca Mountain site. To date, we have obtained and maintained over 40 permits associated with air quality, underground injection control, drinking water, wastewater discharge, water appropriation, and land management. We continued to submit to the Nevada Division of Environmental Protection and other regulatory agencies the quarterly and annual compliance reports required to maintain these permits.

We maintained communication with numerous Federal and State agencies on compliance matters. We continued to maintain 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 to allow scientific investigations such as seismic studies to continue at Yucca Mountain and at remote sites in Southern Nevada and California.

Historic preservation

Consultations and interactions with 17 Native American Tribes and organizations continued under the Programmatic Agreement between the Department and the Advisory Council on Historic Preservation. We coordinated visits to the Yucca Mountain site by Native American Tribes, held two meetings to update all 17 Native American Tribes and organizations on project activities, and attended a variety of national meetings. We initiated consultations with Native American Tribes and organizations on matters pertaining to the Native American Graves Protection and Repatriation Act.

Waste minimization and management

The environmental program continued to be an important part of day-to-day operations at the site. It included management of hazardous and solid waste disposal; waste minimization, recycling, and pollution prevention efforts; and operation of hazardous waste accumulation areas in compliance with the Resource Conservation and Recovery Act. The small amount of hazardous waste generated was transported to an off-site facility that is permitted by the Environmental Protection Agency (EPA) to manage hazardous waste. Waste continued to be managed appropriately, with no hazardous or toxic material released to the environment.

Other environmental efforts

To verify that these activities are performed in full compliance with environmental requirements and regulations, we continued our environmental assessment program. It includes a thorough review of project activity compliance with applicable permits, as well as frequent, unannounced surveillance checks in the field. Project personnel conducted approximately six environmental assessments and nearly 500 environmental field surveillances. Rigorous assessments and surveillances contributed to our success in avoiding, minimizing, and mitigating any adverse environmental impacts and ensuring full regulatory compliance.

International Efforts

In support of the U.S. geologic disposal program, OCRWM continued to pursue international efforts through existing and renewed bilateral agreements with other nations and through formal membership in international organizations: the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development, and the International Atomic Energy Agency (IAEA). The focus of these efforts is technical work that will enhance our scientific investigations of the Yucca Mountain site. Throughout Fiscal Year 1998, visitors from other nations continued to visit the Yucca Mountain site to learn about our work.

Along with ten other nations, OCRWM became a member of the newly formed International Association for Environmental Disposal of Radioactive Waste. Its purpose is to intensify international cooperation by facilitating the exchange of views on policy issues and stimulating joint research and development projects.

At the annual meeting of the IAEA in Austria in September 1998, Secretary Richardson announced that the Department will sponsor a conference on the policy and technical aspects of geologic disposal. Several international organizations have been offered co-sponsorship of the conference, including the IAEA. The conference is further being coordinated with the National Academy of Sciences.

During Fiscal Year 1998, OCRWM worked with Russian officials toward formalizing a cooperative initiative to develop a repository in Russia for the disposition of Russia's spent nuclear fuel, high-level radioactive waste, and post-cold war surplus nuclear materials. In a September 1998 meeting, OCRWM and Russian officials agreed to develop a bilateral agreement for carrying out this work. It is expected that pooling Russian and U.S. technical expertise will directly benefit both OCRWM's site characterization program at Yucca Mountain and Russia's repository initiative.

OCRWM was instrumental in having the NEA conduct an international review of progress in high-level radioactive waste disposal. The resulting document, to be completed in 1999, will show that, even with temporary setbacks in some programs, the international consensus on geologic disposal as the preferred means of dealing with high-level radioactive waste is intact.

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